ANALYSIS OF THE MOVEMENT INITIATION PROBLEM IN PARKINSON'S DISEASE: PRACTICE AS AN INTERVENTION

By

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Dedicated to Jack and Louise Behrman

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The effects of Parkinson's disease (PD), movement complexity, and practice on performance and learning of rapid, arm-reaching movements were studied. Persons with and without PD practiced two, rapid arm-reaching tasks with movement complexity manipulated by the number of steps in a movement sequence and the number of directional changes in the movement. The tasks were practiced for 120 trials each across a 2 day period. The response programming stage of information processing was studied by analyzing the overall reaction time latency of each movement and its fractionated sub-components, premotor and motor time. Movement execution speed was analyzed by recording movement times for each task. A learning effect for practice was studied by comparing the responses for a pretest to those for immediate (10 min rest interval) and delayed retention tests (48 hour rest interval). The complexity by test session results of this study demonstrated that, initially and following practice, persons with and without PD demonstrated similar response programming as manipulated by movement complexity. Reaction and premotor times supported a movement complexity effect. With practice of the two arm-reaching tasks, both persons with and without PD exhibited a learning effect for response programming and movement times and a diminished movement complexity effect for each of the retention intervals. Transfer of practice for the rapid, arm-reaching skill to performance of a manual dexterity skill, the Box and Block Test, was also studied. Transfer of skill was analyzed by comparing the dexterity scores (the number of blocks transported in 60 sec) performed prior to and after practice of the arm-reaching tasks. Persons with PD demonstrated a deficit for timed manual dexterity. Following practice of the arm-reaching tasks, persons with and without PD improved their manual dexterity indicating a possible transfer or test-retest effect. This study demonstrated that participants with PD performed response programming of rapid, arm-reaching tasks of varied movement complexity as well as the control participants and that practice had a similar learning effect for persons with and without PD.

CHAPTER 1
INTRODUCTION

Parkinson's disease (PD) is a central nervous system degenerative disorder that affects older persons and causes movement dysfunction. One of the primary movement disorders resulting from PD is difficulty initiating movement, a problem known as akinesia (Delwaide & Gonce, 1993). In the motor behavior literature, slowness in movement initiation in older adults, as measured by reaction time (RT), has been associated with deficits in the information-processing stage of response programming (Light, 1991a; Light & Spirduso, 1990).

Smith (1968), Sternberg (1969), Theios (1975), and Kerr (1978) have each proposed theoretical models of information processing as a mechanism of study and analysis of human motor behavior. Though the number and functions of each information-processing stage differ across models, the stages most commonly identified among models are stimulus identification, response selection, and response programming. Researchers examining motor performance in normal aging have agreed that deterioration of RT to an environmental stimulus is subsequent to central nervous system processes as described in information-processing models (Light, 1991a). Independent manipulation of variables for each stage of information processing has indicated that stimulus identification (Botwinick, 1972; Hines, Poon, Cerella, & Fozard, 1982), response selection (Baron, Menich, & Perone, 1983; Jordan & Rabbitt, 1977), and response programming (Larish & Stelmach, 1982; Light & Spirduso, 1990) can account for the aging deficit in RT. To the contrary, peripheral processes such as muscle contractile speed and nerve conduction have not accounted for delays in RT.

The focus of this study is the response programming stage of information processing. Response programming is the stage following stimulus identification and response selection in which the actual movement response is structured and activated (Schmidt, 1988). One factor which has been determined to influence the delay in RT attributable to response programming in normal young and older adults is response complexity (Christina, 1992; Henry & Rogers, 1960; Light & Spirduso, 1990; Light, Reilly, Behrman, & Spirduso, in press). In the seminal work of Henry and Rogers (1960), the researchers concluded that response complexity, defined as the difficulty of the response to be performed after a stimulus, affected reaction time. More recently, researchers have found that for healthy adults, increases in the complexity of the movement response results in significant increases in RT, specifically response-programming time (Christina, 1992). The response complexity effect, as defined by Christina (1992), describes the increase in the time required to prepare to initiate (RT) a learned movement response, to be performed as rapidly and accurately as possible, when the response becomes more complex. Light and Spirduso (1990) referred to the significant increase in RT, as a result of specifically increasing the complexity of a movement response, as a movement complexity effect. Altering the difficulty of the actual movement to be executed in response to a stimulus affects the response programming stage and subsequently affects the RT.

The existence of response delays and the specific cause in persons with PD remains controversial (Chan, 1986). Some researchers have observed significantly longer simple reaction times (SRTs) for persons with PD than control subjects (Evarts, Teravainen, & Calne, 1981; Stelmach, Teasdale, & Phillips, 1992), whereas earlier researchers have reported no significant difference in SRTs between the two groups (King, 1959). Furthermore, research findings do not indicate significant differences in the effects of stimulus identification in persons with PD and control subjects. Evidence for a selective impairment in the response selection stage in persons with PD compared to normal adults continues to be debated in the literature as well (Cooper, Sagar, Tidswell, & Jordan, 1994; Evarts et al., 1981; Stelmach, Worringham, & Strand, 1986).

RT differences have been reported in persons with PD when response complexity has been manipulated (Harrington & Haaland, 1991; Rogers & Chan, 1988; Stelmach, Worringham, & Strand, 1987). In two of the studies, RTs of persons with PD were not affected in duration for the more complex responses compared to the predicted increased RTs of control subjects (Harrington & Haaland, 1991; Stelmach et al., 1987). Researchers accounted for the lack of a complexity effect in persons with PD by proposing that these individuals demonstrated a deficit in response programming. Thus, researchers suggested that components of a movement were not programmed as a unit, but as sequential, individual movements. In contrast, Rogers and Chan (1988) ascertained a complexity effect in persons with PD, yet longer RTs for persons with PD compared to control subjects. The nature of the tasks implemented by these three sets of researchers indicates a lack of adherence to a strict definition of movement complexity (Christina, 1992; Fischman, 1984; Henry & Rogers, 1960; Light & Spirduso, 1990) and may account for different findings and conclusions.

Previous studies have not identified the exact nature of the Parkinson's-related response-programming deficits. Moreover, limited research exists concerning the difference between complexity effects for healthy elderly individuals and those with PD. The effects of PD on behavior must be delineated from the effects of healthy aging as a basis for understanding PD and for development of treatment interventions. Therefore, the focus of this study was to investigate the response programming stage of information processing in people with PD as well as the movement complexity effect. To further delineate the central processing effects from the peripheral component, total RT was fractionated by surface electromyography (EMG) into premotor and motor RT (Lofthus & Hanson, 1981; Stelmach et al., 1992). Fractionation provides another level of analysis which may explain differences in the central and peripheral contributions to RT of persons with PD and healthy elderly individuals.

Researchers have speculated that the basal ganglia functions in the initiation and execution of automatic, learned movement sequences (Marsden, 1982, 1984; Marsden & Obeso, 1994). Examination of motor behavior in persons with PD, specific to response programming, serves as a contribution to the converging lines of evidence defining the role of the basal ganglia in motor control and learning. Converging lines of evidence and inference for basal ganglia function are founded in neuroanatomical, neurophysiological, human disease, neural network model, and behavioral studies (Alamy, Trouche, Nieoullon, & Legallet, 1994; Brotchie, Iansek, & Hornes, 1991a; Cheruel, Dormont, Amalric, Schmied, & Farin, 1994; Contreras-Vidal & Stelmach, 1994; Evarts & Wise, 1984; MacKinnon, Kapur, Verrier, Hoole, & Tatton, 1994; Marsden, 1984; Marsden & Obeso, 1994; Wing & Miller, 1984).

In this study, psychological and behavioral investigation perspectives were adopted and PD was selected as the most appropriate human model for examining basal ganglia dysfunction (Marsden, 1984; Wing & Miller, 1984). Thus, persons with PD and age- and gender-matched control subjects were tested for response programming and movement complexity effects. Two different movement responses based on levels of complexity were combined in a simple RT paradigm. Movement complexity was varied by altering the number of movement components (from one to four) and the number of directional changes (from zero to three) (Anson, Wickens, Hyland, & Kotter, 1994; Christina, 1992; Henry & Rogers, 1960; Light, Reilly, Behrman, & Spirduso, in press; Rosenbaum, 1980).

Furthermore, with extensive practice, the contribution of the response complexity effect to RT is known to decrease in healthy subjects (Fischman & Lim, 1991; Hulstijn & Van Galen, 1983; Norrie, 1967a, 1967b; Van Mier & Hulstijun, 1993). Practice is a critical tool used for movement training (Ericsson, Krampe, & Tesch-Romer, 1993) and re-training. The benefits of practice for motor learning in persons with PD have been limited and task specific (Connor & Abbs, 1990; Gabrieli, 1995). The benefits of practice on altering the complexity effect in clients with PD has not been established. Persons with PD and the control subjects practiced the two different movement responses under simple RT conditions on two separate days. The effect of this practice, PD, and its interaction with the movement response complexity was examined to differentiate central processing effects from peripheral changes.

Statement of the Problem

The general purposes of this study were to (1) determine the performance differences between persons with and without PD for each component of speeded-movement responses of varying complexity, (2) examine the differential effects of practice on altering each of the movement-response components in persons with and without PD in tasks of varying movement complexity, and (3) determine transfer of the practiced speeded-movement responses to performance of another motor skill. Specifically, the effects of PD, movement response complexity, and practice on simple RTs and speeded movement responses were studied.

Research Hypotheses

The research hypotheses will be presented according to the following three categories: movement complexity, practice, and transfer of skill acquisition.

Movement Complexity Hypotheses

When compared to the control participants, participants with PD will have significantly slower: (1) overall SRTs, (2) premotor times, (3) motor times, and (4) movement times. When comparing RTs for a simple to more complex movement, control participants will demonstrate a significant increase in (1) overall SRTs and (2) premotor times. When comparing RTs for a simple to more complex movement however, participants with PD will demonstrate less change in (1) overall SRTs and (2) premotor times than matched controls, thus demonstrating deficit behavior.

These hypotheses are consistent with the literature in that persons with PD performing simple movements typically demonstrate slower movements throughout every component of the movement response (Marsden, 1982; Rogers, 1991; Phillips, Muller, & Stelmach, 1989). A movement complexity effect on RT is expected for control subjects as supported by previous findings (Christina, 1992; Light & Spirduso, 1990). For the complexity effect in persons with PD, less change in premotor time is hypothesized based on the findings of Harrington and Haaland (1991), Stelmach et al. (1987), and Jones et al., (1994). Verification of a complexity effect in persons with PD remains controversial. Unremarkable changes in RTs for persons with PD is inconsistent with changes expected due to the movement complexity effect. Researchers have subsequently questioned the ability of persons with PD to functionally program a series of movements into a sequential unit. Consequently, researchers have inferred that normal basal ganglia function is critical to the preparation and initiation of sequential movements and to skill learning.

Slower motor times and movement times are projected for persons with PD regardless of the level of movement complexity. Differentiation of premotor and motor time effects is consistent with previous studies fractionating RT to infer central and peripheral contributions to motor behavior (Christina & Rose, 1985; Stelmach et al., 1992). Slowness of movement, termed bradykinesia, is also a typical movement disorder for persons with PD (Rogers, 1991).

Practice Hypotheses

Participants with and without PD will benefit significantly from practice for (1) premotor times, (2) overall RTs, and (3) movement times. Participants with PD will benefit significantly less from practice than those subjects without PD for: (1) premotor times, (2) overall RTs, and (3) movement times. The means for each of these variables will decrease more for complex movements than for simple movements for both groups.

Practice has a beneficial effect on response programming and RT for normal, healthy subjects with greater effects on complex tasks (Fischman, & Lim, 1991; Fischman & Yao, in press; Norrie, 1967a, 1967b). Persons with PD have shown the capacity to improve motor performance on varying motor tasks (Frith, Bloxham, & Carpenter, 1986; Soliveri, Brown, Jahanshahi, & Marsden, 1992; Worringham & Stelmach, 1990), but have not improved to the performance level of control subjects. Generally, the rate of performance change has also been less in persons with PD. As the degree of performance change has varied across studies, it may be task-dependent (Harrington, Haaland, Yeo, & Marder, 1990; Hening, Rolleri, & Gordon, 1994). Reaction times for both PD and control subjects are expected to improve with practice, yet control subjects may present greater improvements (MacRae, Spirduso, & Wilcox, 1988). Persons with PD may require extended practice, particularly for complex tasks (Fischman & Yao, in press), to decrease the performance difference with control subjects (Soliveri et al., 1992).

Transfer of Skill Acquisition Hypotheses

(1) Participants with and without PD will improve on the transfer task scores from pretest to posttest. (2) Participants with PD will score significantly lower on the BBT compared to matched controls for both pretest and posttests. (3) Individuals who demonstrate faster RTs and MTs on the two tasks of varying complexity will demonstrate higher BBT scores. High scores on the BBT are a result of fast RTs and MTs. As persons with PD exhibit slower RTs and MTs compared to control subjects (Marsden, 1982; Rogers, 1991), lower scores on the BBT would be expected for persons with PD. (4) Participants with decreased RT and MT scores from pretest to posttest will also display significant improvements in BBT scores. The BBT is a validated test of timed manual dexterity requiring fast, repetitive hand motions, including grasp and release of identical,

2.54 cm cubes (Desrosiers, Bravo, Hebert, Dutil, & Mercier, 1994). Persons with PD have not been tested for transfer of motor performance from a practiced motor task to a new motor task. Based on the similarity of the practice task and the transfer task requirements, carry-over to BBT performance is speculated for persons demonstrating improved RT and MT performance after practice of the two arm-reaching tasks.

Definition of Terms

Fractionated RT is RT divided into its two sub-components of premotor time and motor time according to the onset of EMG activity.

Information processing model is a model of motor control based on a continuum of stages of information processing from stimulus input to motor output.

Movement complexity is the difficulty of the movement to be executed explained by such factors as sequence length, duration, and sides of the body controlled.

Movement complexity effect is a statistically significant increase in RT as a result of specifically increasing the complexity of a movement response.

Movement time is the time interval between the onset of the movement response and the completion of the movement.

Motor time is the time interval between the onset of EMG activity and the initiation of the movement response.

Premotor time is the time interval between the onset of the movement initiation stimulus and the onset of EMG activity.

Reaction time is the time interval between the onset of the movement initiation stimulus and the onset of movement response.

Response complexity is the difficulty of a response manipulated by altering stimulus identification, response selection, or response programming stages of information processing

Response programming is the stage of information processing in which the actual movement is structured and activated; the transformation of a selected, cognitive response code to a motor response code as execution commands for the task.

Response selection is the stage of information processing after stimulus identification at which a motor response is selected.

Response time is the time interval between the onset of the movement initiation stimulus and completion of the movement response.

Stimulus identification is the stage of information processing at which the environmental information or stimulus input is encoded and identified.

Transfer of skill is the influence that practice or experience of one type of task may have on performance of another, different task.

Assumptions

This study enlisted the following three fundamental assumptions: (1) the movement complexity effect on RT is robust and well-documented as an element of response programming, (2) practice is one of the most influential variables in skill acquisition, retention, and transfer. and (3) basal ganglia function may be inferred from examination of motor behavior in persons with PD.

Limitations

Limitations of this study are imposed due to the population criteria, disease process, task specificity, practice and feedback parameters, task validity, and testing validity. The population studied included 15 persons with PD who are right-hand preferred, community-dwellers, ambulatory (Level II and III Hoehn and Yahr scale), have normal cognitive function, and have no history of other neuromuscular disorders and 15 age- and gender-matched participants. Inferences from this study can thus be made only to persons with PD matching these critieria. Inferences to basal ganglia function will be made cautiously recognizing that PD also involves other areas of the central nervous system.

The tasks which participants will practice involve two fast, right arm-reaching patterns at different levels of movement complexity. Thus, inferences will be limited to performance of ballistic, upper extremity movements. Studies involving other motor tasks, levels of movement complexity, or parameters of movement complexity may render different findings.

Participants will complete a total of 20 pre-test trials and 120 practice trials for each of the two arm-reaching movements across a two-day period prior to postttesting. Summary feedback will be provided to the participants with the goal of improving response times for each movement pattern. Each person completing the study will receive $50.00. An additional monetary incentive will be provided for the fastest response time after practice for one individual with PD and one individual without PD. Persons practicing such tasks with a different practice schedule, number of trials, feedback, goal, and incentives may perform differently than observed in this study.

This study will be conducted in a laboratory environment. The ecological validity of the findings may be limited due to the testing environment, as well as the novelty of the movement task. Inclusion of a transfer task of a validated task of manual dexterity will contribute to the ecological validity of the study.

Significance of the Study

The review of the literature and findings from this study may advance knowledge of the basal ganglia role relative to motor control and learning and may directly affect intervention and rehabilitation strategies for persons who have PD. From this foundation, four specific points for significance of the proposed study will be addressed.

First, this study will enhance our understanding of the specific motor problems associated with PD. The slowness in movement behavior associated with aging in healthy adults has been attributed to changes in every stage of information processing. However, the slowness in movement behavior for persons with PD has yet to be clarified for response programming. Identifying the contribution of the response-programming stage to Parkinson's akinesia may appropriately redirect treatment efforts.

Second, comparing lines of evidence from behavioral science and neurophysiological studies (motor behavior research in persons with PD and research of basal ganglia function) may together provide a better understanding of motor control and its organization specific to the acquisition and performance of automatic, learned movement sequences. Examination of response programming, movement initiation, and execution in persons with PD for complex, practiced, speeded responses will thus contribute to our understanding of basal ganglia function, motor control, and motor learning.

A third point of significance is that examining the effect of practice for response programming in persons with and without PD will aid in determining the efficacy of extensive practice as a treatment intervention for persons with PD. Practice continues to be a predominant tool of intervention for training and retraining motor skills, yet practice has had limited, task-specific effects for persons with PD.

Lastly, transfer of skill acquisition has not been explored in persons with PD. This study included a transfer task, the Box and Block test (BBT), to examine the effect of practice of fast, arm-reaching movements on BBT performance. The BBT is a standardized, validated test of manual dexterity. The notion of transfer remains a critical principle of skill acquisition and is pertinent to an understanding of whether the benefits of practice of response programming in persons with and without PD is task specific or may be generalized to other tasks.

CHAPTER 2
REVIEW OF THE LITERATURE

The review of the literature is presented in six sections. First, an overview is provided concerning the general effects of PD relative to motor function. Second, the information-processing model of motor control is introduced as a mechanism for analysis of motor dysfunction in persons with PD. For the purposes of the proposed study, the response-programming stage of information processing is described, including the response complexity effect. In addition, the effects of age and of PD on the response complexity effect are reviewed. Third, practice is discussed relative to its influence on skill acquisition. Specifically, the benefits of practice on motor performance by older adults and by persons with PD, on the response complexity effect, and on transfer of motor skill are addressed. Fourth, current intervention strategies in the rehabilitation of persons with PD are reviewed relative to the proposed study. Fifth, analysis of the movement initiation problem in PD is considered as one component of analysis which will contribute to an integrated understanding of the role of the basal ganglia in motor control and learning. A summary concludes this chapter.

Effects of Parkinson's Disease

Parkinson's disease is a progressive, degenerative disorder of the central nervous system, primarily involving basal ganglia dysfunction. The disease predominantly affects older individuals and results in a broad array of movement problems (Glendinning & Enoka, 1994; Rogers, 1991). The major effect of PD is the diminishing of voluntary and reflexive movements (hypokinesia). More specifically, persons with PD exhibit delay in movement initiation (akinesia), slowness of movement execution (bradykinesia), holding of fixed postures for extended periods (akinesia, rigidity), tremor at rest, decreased or absent associated movements (e.g., arm swing during ambulation), and movement arrest as observed in the freezing phenomenon (Brooks, 1986; Delwaide & Gonce, 1993; Marsden, 1982; Phillips, Bradshaw, Iansek, & Chiu, 1993; Rogers, 1991; Stelmach & Phillips, 1991). The focus of this study is an analysis of the movement initiation problem in PD, from an information-processing model perspective, and an examination of practice as an intervention.

Information-Processing Model of Motor Control

Stages

Motor behavior is viewed on an information-processing continuum from stimulus input to motor output. One of the more accepted information-processing models is the three-stage model which includes stimulus identification, response selection, and response programming (Schmidt, 1988). (See Figure 1.) Previous researchers have validated the use of the motor-control information-processing model to examine the basis of movement disorders in PD (Brooks, 1986; Phillips & Stelmach, 1992; Phillips et al., 1989; Wing & Miller, 1984). Although the information-processing model, using RT measurements, is commonly reported in the literature on PD, the types and causes of information-processing delays are controversial (Evarts et al., 1981; Flowers, 1976; Marsden & Obeso, 1994; Montgomery, Gorman, & Neussen, 1991; Rogers & Chan, 1988).

Due to the relatively late age of onset of PD, the effects of aging on information processing must be considered and delineated from the effects specific to PD. Numerous age-related changes in the central nervous system lead to slowing of information processing and execution (Birren, Woods, & Williams, 1980; Dustman, Emmerson, & Shearer, 1994). Variability of performance between and within individuals also increases as successive age

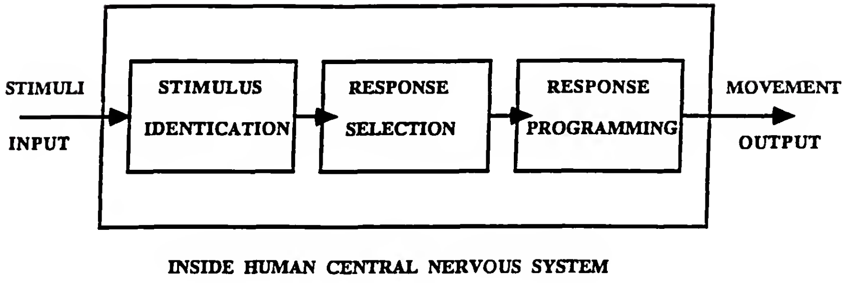

Figure 1. Information-processing model of motor control (Schmidt, 1988).

groups are compared (Rabbitt, 1993). Older adults, though, typically demonstrate slower movement response times than younger adults for both RT and MT components (Salthouse, 1985). Increases in the information-processing requirements of a task result in greater demands of mental processing and longer RTs for older individuals compared to younger persons. Older adults appear to be more sensitive to changes in complexity of a psychomotor task for all stages of information processing compared to younger adults (Light, 1990).

Task complexity can be altered by manipulating variables for any of the information-processing stages (Light, 1991b; Schmidt, 1988), resulting in RT changes. Thus, increasing the intensity of an onset stimulus light affects the stimulus identification stage and results in a faster RT. Increasing the number of response alternatives affects the response selection stage and delays RT (Hick, 1952; Hyman, 1953). Manipulating the difficulty of the actual movement to be performed affects the response programming stage of information processing and will increase or decrease RT, accordingly (Light & Spirduso, 1991a).

RT delays in persons with PD have been consistently reported in recent literature (Sheridan, Flowers, & Hurrell, 1987; Stelmach et al., 1992). However, PD appears to have differential effects on each of the information processing stages. Investigators report that stimulus identification appears unimpaired in persons with PD (Bloxham, Mindel, & Frith, 1984; Stelmach & Phillips, 1991). However, existence of Parkinsonian-related deficits in response selection and planning are controversial (Brown, Jahanshahi, & Marsden, 1985; Brown et al., 1993; Cooper et al., 1994; Evarts et al., 1981; Marsden, 1982; Sheridan et al., 1987, Stelmach et al., 1986). The selective impairment of response selection as demonstrated by delays in choice RTs is debated (Cooper et al., 1994; Evarts et al., 1981). Researchers generally agree that the last stage of information processing, response programming, is the stage most disturbed by PD (Brooks, 1986; Delwaide & Gonce, 1993; Sanes, 1985; Stelmach et al., 1986). However, the exact elements of the programming problems have not been identified (Harrington & Haaland, 1991; Roy, Saint-Cyr, Taylor, & Lang, 1993).

Response Programming

Response complexity effect. Response programming has been described as a transformation of a selected, cognitive response code, i.e., an abstract idea of a response, to a motor response code as execution commands for the task (Henry & Rogers, 1960; Schmidt, 1988). Response complexity is one of the response-programming variables studied extensively by previous investigators. Since Henry and Rogers' (1960) initial work, in which they observed longer RTs in the performance of more complex movements, investigators' findings have continuously supported this observation (Christina, 1992).

The use of RT latency as a measure of programming time is based on the view that greater central nervous system preparation time is required to coordinate and organize more complex movements. This increased central nervous system preparation causes slower movement initiation or slower RTs. Furthermore, fractionating RT into its subcomponents allows for localization of the central processing time to premotor time, as opposed to the peripheral contribution of motor time (Lofthus & Hanson, 1981). From these findings, researchers have inferred that more complex movements require an increase in the amount of time to program the movement, a phenomenon termed the response complexity effect (Christina, 1992). The significant increase in RT as a result of specifically increasing the complexity of a movement response has been more accurately described as the movement complexity effect (Light & Spirduso, 1990).

Many factors have been studied as possible contributors to movement complexity, including number of movement parts (Fischman, 1984; Henry & Rogers, 1960); number of controlled sides of the body (Light & Spirduso, 1990; Rosenbaum, 1980), movement duration (Klapp, 1975), and movement direction (Fischman, 1984). For this study, movement complexity will be manipulated by the number of steps in a movement sequence and number of directional changes in the movement (Anson, Wickens, Hyland, & Kotter, 1994; Christina, 1992; Christina, Fischman, Lambert, & Moore, 1985; Christina & Rose, 1985; Fischmann; 1984, Light, Reilly, Behrman, & Spirduso, in press).

Aging and the response complexity effect. As task complexity increases, the difference between response speeds of younger versus older individuals becomes more extreme (Birren & Botwinick, 1955; Cerella, Poon, & Williams, 1980; Jordan & Rabbitt, 1977; Light, 1991b; Tolin & Simon, 1968). Specific to response programming, as the complexity of the movement response is increased, RTs increase significantly, also with increasing disparity between RTs of older and younger subjects (Light & Spirduso, 1990; Light, Reilly, Behrman, & Spirduso, in press).

Parkinson's disease and the response complexity effect. A movement complexity effect has not appeared consistently when comparing healthy-old individuals and those with PD. Complexity has been manipulated by altering the required type of movement response (ballistic vs. tracking) (Rogers & Chan, 1988), control of simultaneous movements (Benecke, Rothwell, Dick, Day, & Marsden, 1986; Benecke, Rothwell, Dick, Day, & Marsden, 1987a; Stelmach & Worringham, 1988), repetitiveness or task homogeneity (Harrington & Haaland, 1991), and sequence length (Benecke, Rothwell, Dick, Day, & Marsden, 1987b; Harrington & Haaland, 1991; Jones et al., 1994; Rafal, Inhoff, Friedman, & Bernstein, 1987; Stelmach et al., 1987).

The findings of Stelmach et al. (1987) indicated that differences in response programming for persons with PD in comparison to control subjects by a lack of sequence length effect for increased RT. The researchers also noted an increase in number of errors in responses with increased sequence length. Harrington and Haaland (1991) similarly observed no significant changes in RT for homogeneous responses and a lack of significant increase in RT for increased sequence length of heterogeneous responses. Intratask response times increased as sequence length increased for persons with PD, as well as increased errors identifying the number of sequence changes even after precue. Thus, persons with PD responded differently than persons without PD to changes in movement complexity with regard to RT and intratask response time. As indicated by these researchers, these observations may be attributed to an impairment of preprogramming of entire movement sequences or deterioration of the execution plan for the movement sequence.

Benecke et al. (1987) observed that persons with PD perform sequential movements slower than normals and demonstrated delays in switching from one movement to the next. The tasks involved a two-part sequence consisting of hand motions (isometric squeeze or isotonic cutting) and/or elbow flexion (isotonic). These researchers suggested that PD impairs the ability to organize an overall motor plan and subsequently the capacity to switch from one program to another in a sequence. Benecke et al. further hypothesized that such organization occurs under the direction of basal ganglia activity in association with the supplementary motor area.

Jones et al. (1994) also did not find a complexity effect for persons in PD as observed in the down time, the time taken to initiate movement from the button preceding a sequence of three to five taps. Subjects performed a sequence of three, repetitive, finger tap sequences. From their analysis, the researchers attributed deficits in sequential movements to dysfunction in the initiation of submovements within the sequence of sequences.

In contrast, Rafal et al. (1987) found no differences in the response programming effects for sequential movements of one to three components for persons with and without PD, as indicated by simple RTs and intra-response intervals. The researchers did find that Parkinsonians were slower in movement initiation and execution of sequential finger movements than control subjects.

Comparing across movement complexity studies, researchers have not adhered strictly to definitions of complexity as described in the motor behavior literature (Christina, 1992; Henry & Rogers, 1960; Phillips et al., 1992). For example, the use of a ballistic movement versus a tracking movement would be described more appropriately as a comparison of open-loop to closed-loop movements than a manipulation of task complexity (Rogers & Chan, 1988). Performance differences for persons with PD, though, were accounted for by disturbances in central processing of complex tasks. The heterogeneity of sequential movements may have allowed biomechanical limitations to affect performance for persons with PD, not actualized under other conditions (Anson, 1982; Harrington & Haaland, 1991). The level of complexity of some tasks (i.e., finger tap repetition) may not be complex enough to generate differences in SRT conditions or in response programming (Jones et al., 1994; Rogers, 1991). Performance of tasks in which sequential movements must be programmed on the basis of internal sensory cues may differ from performance of tasks in which sensory cueing concerning the sequence is provided throughout movement performance (Harrington & Haaland, 1987; Jones et al., 1994). Heterogeneity within the population with PD may account for inconsistency in findings, especially when subjects representing extreme levels of disability are included in the same experimental group (Evarts et al., 1981; Zetusky, Jankovic, & Pirozzolo, 1985).

Practice

Motor Performance

Practice generally results in improved motor skill performance and is reported to be the most powerful variable for motor skill acquisition (Ericsson & Charness, 1994; Lee, Swanson, & Hall, 1991; Schmidt, 1988). As a learner practices and improves in the performance of a motor skill, he or she progresses through a series of stages of motor learning: Cognitive, associative, and autonomous (Fitts, 1964; Fitts & Posner, 1967). These stages are characterized by a transition from performance dependent upon cognitive learning of the task, high attentional demand to the task requirements, verbalization of the steps, external cueing and feedback (Christina & Corcos, 1988); to performance focusing on error-detection and a combination of self-feedback and external feedback; to performance of the skill automatically requiring minimal attention to the task itself or a shift in attentional resources, with remaining attentional capacity available for strategy or for dual task performance (Ericsson et al., 1993; Logan, 1985; Marsden, 1984).

Practice-related improvement in motor performance can be measured in numerous ways including changes in response times, number of errors, accuracy, consistency, coordination patterns, retention, and transfer test performance (Schmidt, 1988). From an information-processing model of motor control, performance improvements attributed to changes in central-processing time may be measured by premotor RT, whereas changes in the peripheral components may be measured by motor RT and movement time (Clarkson & Kroll, 1978).

Practice Effects on Motor Performance in Adults

In the motor learning literature, movement practice is reported to be the most influential factor for motor-skill acquisition among all age groups (Behrman, Vander Linden, & Cauraugh, 1992; Fitts, 1964; Lee, Swanson, & Hall, 1991; Light, 1991; Salthouse & Somberg, 1982; Salthouse, 1990; Schmidt, 1988; Spirduso & MacRae, 1990). In particular, speed of movement responses is known to be extremely practice dependent for the general healthy population. Older adults, however, may require extended practice periods compared to younger adults to achieve motor performance improvements (Carnahan, Vandervoort, & Swanson, 1993; MacRae, Spirduso, & Wilcox, 1988; Murrell, 1970; Murrell, Powell, & Forsaith, 1962; Salthouse, 1990).

Using an animal model of aging, MacRae et al. (1988) determined that age-related impairments in RT can be reduced and eliminated with extensive practice. Such impairments occur in conjunction with changes in the nigrostriatal dopamine system and are found in the normal, aging population and in persons with PD. Furthermore, these researchers observed high positive correlates for RT performance, age, and nigrostriatal dopamine function. Extensive practice was suggested as a mechanism for improvement of RT in both aging individuals with and without PD.

Practice Effects on Motor Performance in Persons with Parkinson's Disease

Researchers have determined that persons with PD can benefit from movement practice for altering overall SRT (Worringham & Stelmach, 1990), overall response times (Frith et al., 1986; Soliveri et al., 1992), and time-on-target (Harrington et al.,1990), yet motor learning abnormalities persist with learning outcomes being reduced and task-specific. Frith et al. (1986) concluded that persons with PD practicing semi-predictable and novel tasks demonstrated learning and development of automaticity. Performance by persons with PD, however, was worse than controls and lacked a reminiscence effect seen in controls. These researchers proposed that persons with PD will have difficulty in the sequencing of a novel task (demonstrating deficits in using prior knowledge or experience). However, with extensive practice, it is suggested that automaticity can be achieved.

Soliveri et al. (1992) also observed improvements in performance of a buttoning task by persons with PD, yet they required more practice than control subjects to achieve similar buttoning speeds. Improvements in performance by persons with PD practicing under dual task conditions provided further evidence for their capacity for skill improvement. The researchers cautioned that limitations in improvement may be attributable to an abnormal motor system as opposed to a deficit in learning.

From a review of the limited number of studies in which persons with PD practiced motor skills of novel or familiar tasks (five studies between 1986 and 1993), practice does appear to have beneficial effects. Practice time and schedules have varied including practice to performance criterion (Roy et al., 1993), practice on one day (Frith et al., 1986; Soliveri et al., 1992), and practice across two to three days (Harrington et al., 1990; Worringham & Stelmach, 1990). Continuous tasks were practiced in two studies and discrete tasks practiced in three studies. The total number of practice trials for two studies using discrete tasks was 20 and 192 (choice RT). The number of practice trials and the extent of practice across days by persons with PD has been limited in these studies. Investigation of the effects of relatively extensive practice in persons with PD is warranted.

Practice Effects and Response Complexity

Practice decreases the movement complexity effect in healthy-young adults (Brown & Carr, 1989; Fischman & Lim, 1991; Fischman & Wan-Xiang Yao, (in press); Hulstijn & Van Galen, 1983; Norrie, 1967a, 1967b; van Mier & Hulstijun, 1993) and between healthy-young and old adults (Light et al., in press). Older adults practicing two arm-reaching tasks of varying complexity reduced simple RTs more than did younger, adult subjects and to the point of equivalence to the young practice group (Light et al., in press).

To date, practice has been determined to be beneficial to motor learning in persons with PD, yet differences in motor learning and its effects relative to PD have been marginally described (Worringham & Stelmach, 1990). Movement practice and its benefit to response programming in persons with PD has not been sufficiently studied. The effect of practice on altering RT, in particular the response complexity effect and the execution of movement sequences, in persons with PD has yet to be determined (MacRae et al., 1988).

Performance of discrete, sequential tasks of varying complexity comprises a significant component of normal, functional voluntary movement (Wing & Miller, 1984). Marsden (1984) noted that the deficit in persons in PD in initiating and executing automatic learned movement sequences may affect their capacity to learn a motor skill. The effects of practice on learning such tasks by persons with PD has not been assessed. The relative permanence of practice effects in persons with PD has also not been addressed in any motor skill training or practice study to date. Furthermore, the transfer of skill acquisition has not been examined in this population. Transfer of skill acquisition is defined as the influence that practice or experience of one type of task may have on the performance of another, different task (Schmidt & Young, 1987). Application of the principle of transfer is important in designing efficient strategies for rehabilitation of persons with PD (Winstein, 1991; Winstein, Gardner, Barto, & Nicholson, 1989). The specificity or generalizability of training for performance of rapid, arm-reaching movement sequences will be examined. Investigating these three aspects of motor learning: practice, retention, and transfer in persons with PD performing sequential tasks of varying complexity will aid in clarifying the motor learning potential of persons with PD, as well as address the analysis of their movement initiation problem.

Intervention Strategies for Rehabilitation in Parkinson's Disease

Therapeutic interventions to improve motor function in persons with PD have included general exercise, range of motion, relaxation techniques, stretching activities, external cueing, and practice of movements (Schenkman et al., 1989; Turnbull, 1992). The efficacy of practice as an intervention for skill learning and transfer has not been determined in patients with PD. Analysis of the effects of practice on speeded movement performance with practice would provide insight into the nature of the movement disorder with PD, and to the specific benefits of practice. Awareness of the impact of practice may aid in treatment selection. Practice, as a direct intervention, may be beneficial to improve function. Alternatively, compensatory strategies such as auditory or visual cues may improve function (Morris, Iansek, Matyas, & Summers, 1994a; 1994b).

Physical therapists are concerned with issues of complexity when attempting movement retraining. The movement retraining progresses from simple to more complex movements by adding limb movements, increasing the duration of tasks, and varying the synchronicity of movements (Light, 1991b). This type of progressive task difficulty is consistent with the definition of movement complexity and is thus used as a means of treatment progression. Changes in the overall RT via the response programming stage of information processing (Christina, 1992; Schmidt, 1988) would be expected to be congruent with changes in the level of movement complexity. With extended practice of complex movements, overall RT is expected to decrease indicating improvements in central processing time and performance.

Analysis of Movement Initiation in PD: Contribution to Motor Control Theory

The study of motor behavior, how movements are controlled and learned, entails a synthesis of several disciplines including neurophysiology, behavioral science, and biomechanics. The study of movement disorders provides an additional mechanism to examine brain function relative to motor behavior. In this manner, knowledge of the structures which are dysfunctional due to disease or injury and awareness of the remaining behavior of the organism are instructive (Phillips et al., 1989; Phillips & Stelmach, 1992; Teitelbaum, 1986, 1994). Examination of a movement disorder often serves to define the relationship of the involved brain structure and function. From this perspective, researchers view the study of persons with PD, resulting from nigrostriatal path damage, as a "window to basal ganglia function" (Contreras-Vidal & Stelmach, 1994) and to human information processing relative to skill learning and memory (Gabrieli, 1995). The behavior of the diseased or injured organism may further contribute to an understanding of how behavior is organized and to the principles by which the remaining structures contribute to function.

The basal ganglia are sub-cortical components of the human neural, motor system. In a hierarchical model of motor control, the basal ganglia affect movement outcomes indirectly by preparing for them and adjusting for them via multiple parallel circuit loops to and from the cortex (Alexander, DeLong, & Strick, 1986; Brooks, 1986; Hoover & Strick, 1993). Two primary neural circuits of the basal ganglia involved in execution of learned movement patterns are the putamen and the caudate circuits. The putamen circuit receives inputs from premotor, supplemental motor, and somatic sensory areas of the cortex with outputs, through the thalamic relay, primarily to the primary motor cortex. In contrast, the caudate circuit receives inputs from the association areas of the cortex (areas integrating motor and sensory information), and sends outputs to the premotor, supplemental motor, and somatic sensory areas of the cortex. Thus, output from the caudate circuit is primarily to accessory motor regions.

Researchers have speculated that the basal ganglia functions in motor sequencing, motor learning, and automatic execution of learned motor plans (Brooks, 1986; Graybiel, Aosaki, Flaherty, & Kimura, 1994; Marsden, 1982; Rogers, 1991; Seitz & Roland, 1992). According to Marsden (1982), as a motor skill is practiced and learned, the basal ganglia functions increasingly to automatically and accurately run the motor plan. Other researchers agree with this perspective describing the role of the basal ganglia relative to a continuum of automaticity in movement performance (Logan, 1985; Marsden, 1984; Teitelbaum et al., in press). At one end of the continuum, the elite skilled athlete or musician represents the height of automatic movement performance. Persons with PD exhibit diminished automaticity (or none at all); the other extreme of the continuum. As the capacity for automaticity in motor performance diminishes or is altered by PD, reliance on cognitive control for motor behavior becomes necessary in individuals with PD (Fitts, 1964; Teitelbaum et al., in press).

Based on animal studies, researchers have suggested that the basal ganglia generate phasic neuronal activity, functioning as internal motor cues for movement components in a sequence dependent upon the predictability, automaticity, or skill level of learned movement sequences (Brotchie, Iansek, & Horne, 1991b, 1991c). Thus, increases in basal ganglia activity may be associated with performance of predictable movements after prolonged practice or repetition to achieve automaticity. Furthermore, the internal motor cue signals the cessation of one movement component in a sequence, allowing execution of the next movement in the sequence. Seitz and Roland (1992), using regional cerebral blood flow (rCBF) studies found the basal ganglia to be significantly involved in the advanced stages of learning and establishment of a motor program for a complex, rapid finger movement sequence in healthy individuals. Their findings were consistent with their earlier work in which overtraining of performance of sequential movements was associated with rCBF increases in the basal ganglia (Roland, Meyer, Shibasaki, Yamamoto, & Thompson, 1982). MacKinnon et al. (1994) have further identified differences in basal ganglia pathways for repetitive finger opposition movements compared to the same movements performed intermittently by humans.

From a behavioral perspective, researchers found that patients with PD demonstrate both prolonged RTs and MTs of movement components in a learned movement sequence compared to control subjects (Georgiou et al., 1993). These findings are consistent with the view of hypokinesia as a deficit in the function of internal cues for performance of learned movement sequences. Benecke et al. (1987) similarly observed delays in persons in PD relative to normals in switching from one program to another in a sequence.

Researchers proposing a simulated model of neuroanatomical, neurophysiological, and neurochemical function of the basal ganglia for simple and complex sequential movements support the role of the basal ganglia in the initiation and execution of movement (Contreras-Vidal & Stelmach, 1994). Dopamine depletion, as demonstrated through their model, may account for various motor disorders, such as akinesia, associated with PD. Other models of information processing in the basal ganglia also advance the basal ganglia as critical in movement initiation (Graybiel & Kimura, 1995) and in skill learning (Gabrieli, 1995).

The works of Brotchie et al. (1991), Georgiou et al. (1993), and Benecke et al. (1987), as described earlier, are examples of the complementary contributions of neurophysiology and behavioral science to an understanding of the role of the basal ganglia in motor control. From this perspective, this study will examine the response complexity effect (Christina, 1992) relative to movement initiation delays and the motor behavior of persons with PD. The function of the basal ganglia may be inferred from such an analysis and combined with neurophysiological research serve to enhance our understanding of the contribution of the basal ganglia to motor control. Movement behavior and the effects of practice, as will be described by comparing persons with and without PD, can further elucidate the importance of movement preparation, learning, and automaticity in the performance of predictable, simple and complex movements.

Summary

Akinesia is a prominent movement problem contributing to the functional decline in persons with PD. From a motor behavior perspective, the theoretical basis for this phenomenon may lie in the movement complexity effect. The movement complexity effect is age-dependent such that older persons are more sensitive to changes in response complexity than younger individuals. A comparison of this effect in persons with and without PD may enhance our understanding of motor function in persons with PD relative to normal aging. Combining this behavioral perspective with previous research from a neurophysiological analysis of basal ganglia function may together advance an understanding of the contribution of the basal ganglia to motor control and learning.

Furthermore, a limited number of researchers have examined the effects of practice on motor performance in persons with PD compared to their peers without PD. Practice is known to be a critical variable in improving motor performance in individuals across the life span. The benefits of practice, specifically of discrete, sequential arm-reaching tasks of varying complexity on learning, retention, and transfer of a motor skill have not been investigated in persons with PD. Investigation of the effects of such practice in persons with PD is warranted to further identify the effects of akinesia and the efficacy of practice as an intervention.

CHAPTER 3
METHODS

Subjects

Fifteen adults diagnosed with PD and 15 age- and gender-matched adults without PD participated in this study. Each group consisted of 10 male and 5 female participants. Table 1 presents a comparison of the descriptive data for the groups with and without PD. Participants were community dwellers and right-hand preferred. With the assistance of family members or caregivers, each participant completed a questionnaire concerning age, onset of PD (if appropriate), educational level, occupation, medications, depression (Geriatric Depression Scale; Yesavage, Brink, et al., 1983) and activities of daily living (Katz Activities of Daily Living -ADL; Katz, Down, Cash, & Grotz, 1970) (Appendix A). The experimenter evaluated all participants for cognitive state and memory with the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975; Bleeker, Bolla-Wilson, Kawas, & Agnew, 1988) (Appendix B). Three participants with PD and scores below standardized normal values for mental state were not included in the study. No participant was on medication with the known side effect of central nervous system slowing. All participants were without a history of other neurologic disease; mental disorder; severe cardiovascular disorder; upper extremity musculoskeletal dysfunction or pain. Persons were screened for normal neurological status (cerebellar function and spasticity of right elbow; Goldberg, 1992) and adequate upper extremity range-of-motion to manuallly perform the experimental arm-reaching tasks (Appendix C). No individuals included in the study demonstrated abnormal neurologic status or proprioceptive or range-of-motion deficits. The experimenter also screened participants for adequate visual acuity and contrast discrimination with habitual correction devices (lenses) (by correct reading of switch-sized printed letters placed on each switch), the ability to identify an auditory response-initiation stimulus (buzzer); the ability to hear and follow instructions; and the ability to manually perform the movements required by the task (Appendix C). All participants in the study demonstrated adequate visual and hearing ability to perform the experimental tasks.

Individuals with PD were classified according to the Hoehn and Yahr (1967) severity of disability rating (Appendix D). People with a disability rating of II or III on the Hoehn and Yahr scale were accepted for participation in this study with 8 participants at Stage II and 7 participants at Stage III. At these two levels, persons with PD exhibit mild to moderate disability, demonstrate bilateral involvement, are still ambulatory, and may exhibit difficulty with balance particularly while walking and turning. Tests and practice sessions were conducted during medication on periods for individuals with PD as verified by the participants. Six participants were being treated with sinemet for PD and 7 participants were medicated with a combination of sinemet and eldepryl.

All participants received $50.00 for completing the study. The two participants, one with PD and one without PD, with the fastest mean response times after practice received a monetary bonus of $50.00. The University of Florida Institutional Review Board for the Rights of Human Subjects Approval provided approval to conduct this study (Appendix E). All participants reviewed and signed appropriate informed consent forms (Appendix F).

Apparatus

A response time (RT and MT) data collection system consisted of numerous components including: a simple-RT auditory stimulus to indicate response initiation; a metronome with earplug to set the warning-signal onset and the intertrial intervals; and five microswitches to record the initial release time and subsequent parts in movement time completion. The microswitches (Able-Net 100) required a minimum of 20-30 g of force for closure and are 6.35 cm in diameter. These equipment components were connected to a

Lafayette Performance-Pack sequential-movement timer (Model 63520) which provided immediate visual digital readouts for the RTs and response times. Activation of the response onset signal simultaneously initiated the clock of the sequential timer to record RTs, MTs, and response times. A signal converter assigned specific signal amplitudes to the response stimulus and switch onset signals for identification during acquisition and analysis. The RT, MT, and EMG signals were collected simultaneously on videotape via a 4-channel, Vetter Scientific Instrumentation Recorder. EMG signals were collected via surface electrodes and an EMG signal-amplification system (Therapeutics Unlimited Inc.) Pre-amplified, active surface electrodes with an amplification of 35x consisted of two silver-silver chloride 1 cm diameter electrodes in an epoxy-mounted pre-amplifier with centers 2 cm apart. During data acquisition, input of all timing and EMG signals was monitored with a 2-channel digital storage oscilloscope (Hitachi-VC 6023). Response component times and EMG activity onsets were identified with the Biopac/ AcqKnowledge data acquisition and analysis software for the MacIntosh computer. See Figure 2 for experiment apparatus.

The apparatus for the Box and Block Test was a wooden box (53.34 cm x 25.4 cm) partitioned into two, equal compartments, 100 (2.54 cm square) wood blocks, and stop-watch (Mathiowetz,Volland, Kashman, & Weber, 1985). See Figure 3 for Box and Block Test apparatus.

Procedures

Box and Block procedures. On Day 1, the experimenter pretested all participants for manual dexterity using the Box and Block Test (Mathiowetz et al., 1985). Practice of the task followed standardized instructions, including a 15 s practice period prior to the 60 s test period. The testing box was placed at the edge of a standard-height table with participants seated facing the box with their hands on each side of the box. Upon verbal command, "Begin", one block at a time was grasped from the right-sided compartment using the right hand, carried over the partition, and released into the opposite compartment. A 60 s test period was timed with a stopwatch with a verbal "Stop" indicating the period's end. The aim of the test was to move as many blocks as possible, one by one, from the right to the left compartment of the testing box during a 60 s period. The experimenter counted and recorded the number of blocks transported during the test.

Arm-reaching tasks. All participants were familiarized with the right arm-reaching tasks. The experimenter demonstrated the tasks, manually guided the participant through each movement pattern, and allowed two practice trials of each movement pattern. The fast, arm-reaching test movements were (1) a simple lateral movement from right to left and (2) a more complex, four-part movement consisting of the simple movement and three additional movements requiring directional changes (Figure 4). The testing and practice schedule consisted of pretests for SRTs on the two movements on Day 1, followed by 2 days of practice (Day 1 and 2), and immediate and delayed retention tests (Day 2 and 3). (See Table 2.) The three test sessions occurred in a Monday, Wednesday, Friday or a Tuesday, Thursday, Saturday sequence. On-medication periods for persons with PD were established prior to each test session according to self-report. No change in on-medication periods for testing occurred in the three-day sequence. Each person was prepared and positioned for testing and practice sessions. For the arm-reaching tasks, the right fingers were positioned flat on the first switch, wrist supported by the table, and arm relaxed. After skin preparation with alcohol wipes, surface electrodes with electrode gel were applied to the right biceps brachii muscle, secured by a double-sided adhesive and circumferential arm wrap. The electrodes recorded EMG activity prior to (baseline activity) and during the movement response (Soderberg, 1992). A ground electrode was attached to the opposite lateral tibia. The EMG signals were led to a high-impedance ($15 m\Omega$ at 100 Hz) differential amplifier (Therapeutics Unlimited Inc.). The resultant amplification allowed a gain of 1,000 to 10,000 with a bandwidth of 20 Hz to 4 kHz. The common mode rejection ratio was 87 dB at 60 Hz (Gerleman & Cook, 1992; Winter, 1980). EMG activity was recorded on videotape by the Vetter Instrumentation Recorder during the testing and practice sessions of Day 1, 2, and 3. Testing and practice were conducted in a quiet room. Each participant sat in an adjustable-height chair such that their right arm was supported on the standard-height table on which the testing apparatus was located.

For the simple movement, following presentation of a verbal, "Ready" signal and an auditory, variable (1 - 3 s) response onset signal, manually activated by the experimenter, the participant released the first switch and moved laterally to the left 12.7 cm to tap the second switch (Figure 4). RT was the time between the onset of the response stimulus (auditory) and the release of the first switch, whereas MT was the time interval from the release of the first switch to the tap of the second switch. Premotor time was the interval of time from the presentation of the response stimulus to onset time of EMG activity. Onset time was defined as a three standard deviation change in EMG activity from baseline EMG activity (Turker, 1993; Walter, 1984). Motor time was the time from onset of EMG to the initiation of the movement response (release of the first switch). Response time was the time between the onset of the response stimulus and the tap of the second switch (completion of the simple movement).

The more complex movement was initiated in the same manner as the simple movement, but three additional movements with directional changes were added (Figure 4). RT measurements were identical to the simple movement condition. MT was the total time required to complete the four-part movement sequence beginning with release of the first switch. Premotor and motor times were measured as described for the simple movement. Response time was the time between the onset of the response stimulus and the tap of the fifth and final switch (completion of the complex movement. The matched-control participants received the identical warning signal patterns and testing order as the corresponding subject with PD. Pretests and posttests consisted of 40 SRT trials (20 trials of each of the simple and complex movements), randomly assigned between participant, without feedback. Catch trials were included to prevent anticipatory false starts (4 per 20 trials) during testing. During testing, trials indicative of false starts, anticipation of the start button by the participant, inattentiveness, or errors in arm-reaching movements were immediately recollected. Practice extended over a two-day period with 120 SRT trials (60 trials of each movement) provided on the first day and 120 SRT trials (60 trials of each movement) occurring on Day 2. Trials were presented in blocks of 10 trials each with the movement type changed after every block (Barth-Neander, Hynes, & Gentile, 1994). During the practice trials, summary feedback concerning response time(s) for each movement type was provided verbally to the subject for the 5, even-numbered trials just completed in the block of 10 SRT trials. Feedback was used in performance evaluation and goal setting by the subject. Trials were presented in 10 s intervals and subjects were provided a 30 s rest between every trial block and a 1 min rest after every 6 trial blocks. Upon completion of the practice session on Day 2, participants rested for 10 minutes. During this time, participants responded to questions of the Mini-Mental State exam and Hoehn and Yahr rating. Following the rest period, an immediate retention test of the arm-reaching tasks and the Box and Block Test was conducted following the identical pretest procedures of Day 1. On Day 3, a 48 hour delayed retention test was conducted and followed the identical pretesting procedure for the arm-reaching task, including recording of EMG activity. Testing and practice schedules remained constant across the three days for each participant (Table 1.) See Appendix G for a review of the power analysis used to determine the sample size, methodological considerations, and preliminary studies performed in preparation for the current study.

Experimental Design and Analysis

Descriptive data for the two subject groups included age, gender, educational level, depression score, and ADL score. Hoehn and Yahr rating, years since onset of disease, and current medications were reported for subjects with PD. The dependent variables for this study were premotor RT, motor RT, total RT, and MT. Before analysis, the raw EMG measures were fully rectified and smoothed and onsets indicated by an algorithm of three standard deviations above the baseline mean (LeVeau & Anderson, 1992; Turker, 1993). The baseline mean was measured across the .5 s time interval of EMG activity prior to the visually-identified deflection of the EMG signal from the baseline. Descriptive data for dependent measures were recorded including means, standard deviations, and ranges. Separate 2 x 2 x 3 (Group x Complexity x Test Session) mixed design ANOVAs were performed to analyze the dependent variables (total RT, premotor, motor time, and movement time) and the effects of practice for RT. Appropriate post-hoc analyses (Tukey's Honestly Significant Difference) were performed. All tests were conducted with the alpha level set at the .05 traditional level.

Separate analyses were conducted for the Box and Block Test, a 2 x 2 (Group x Test Session) mixed design ANOVA. Descriptive data recorded included the mean number of blocks, standard deviations, and ranges. The relationship between the pretest and posttest Box and Block Test performance and arm-reaching performance RT and MT. were analyzed with Pearson Product Moment Correlations.

Table 1.

Descriptive Data for the Participant Groups: Parkinson's Disease and Control

	Group					
	Parkinson's Disease			Control		
Variable	M	SD	Range	M	SD	Range
Age	74	7	56 - 82	73	7	57 - 83
Duration of PD	7	4	1 - 15	---	---	-------
ADL	5.5	1	2 - 6	6	0	6 - 6
Depression	1.9	1.6	0 - 5	.5	.8	0 - 3
Mini-Mental State	28	1.6	25 - 30	29	1.1	26 - 30

Table 2.

Testing and Practice Schedule for the Box and Block Test (BBT) and Arm-reaching Tasks (ART).

	Day		
Procedure	1	2	3
BBT	Pretest		
ART	Pretest 20 trials, simple 20 trials, complex	Practice 60 trials, simple 60 trials, complex	Delayed RetentionTest 20 trials, simple 20 trials, complex
	Practice 60 trials, simple 60 trials, complex	Immediate Retention Test 20 trials, simple 20 trials, complex	
BBT		Posttest	

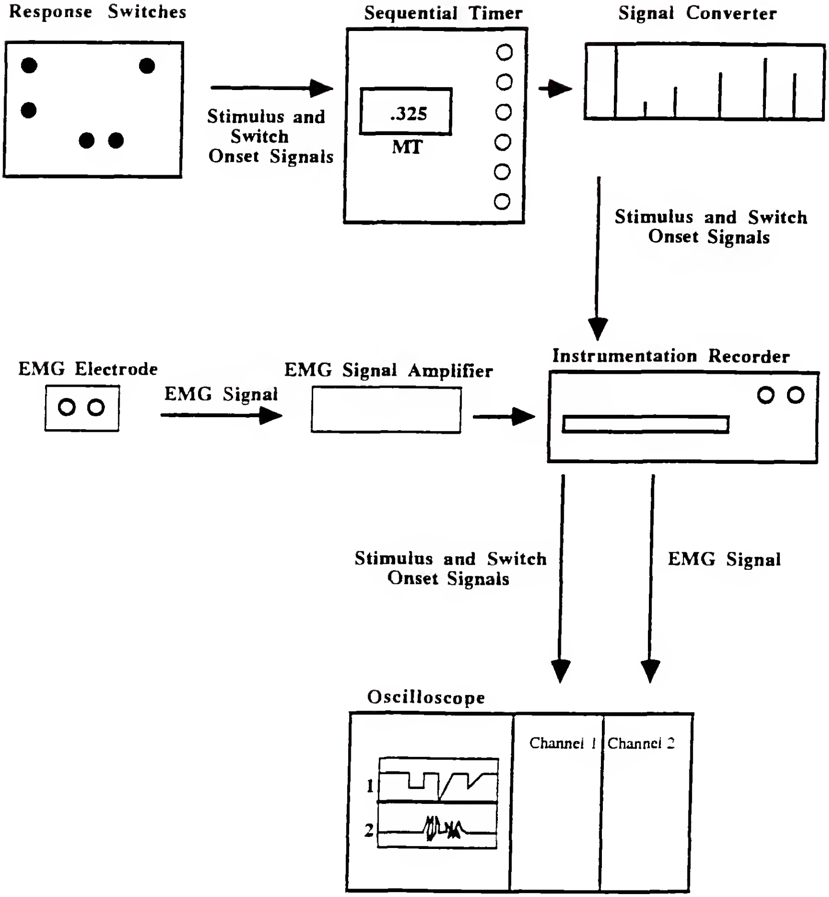

Figure 2. Experiment apparatus including arm-reaching task, sequential timer, signal converter, instrumentation recorder, EMG signal-amplification system, and oscilloscope.

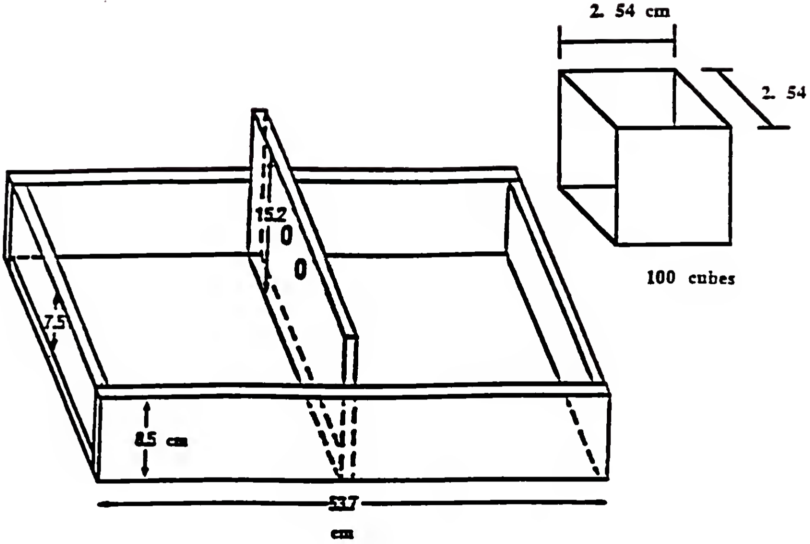

Figure 3. Box and Block Test apparatus.

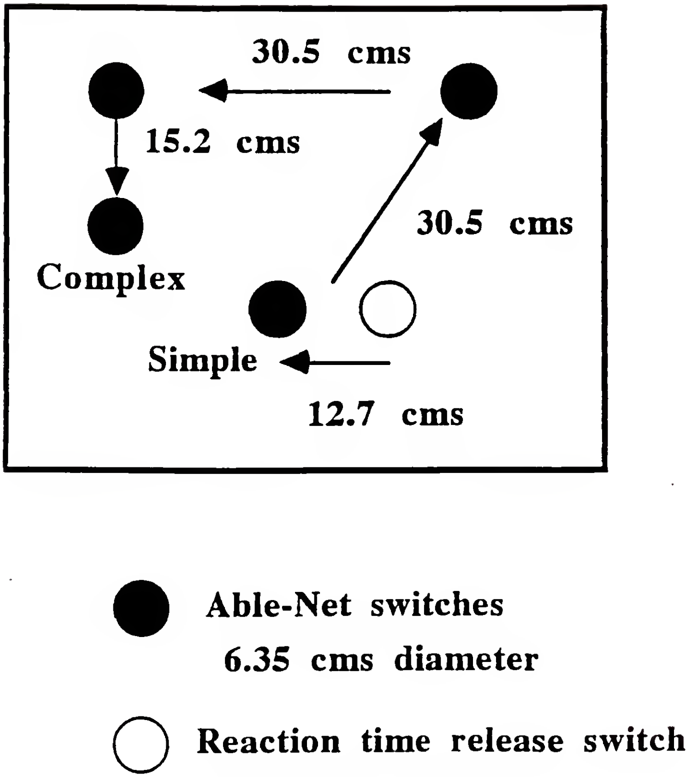

Figure 4. Simple and complex arm-reaching movements.

CHAPTER 4
RESULTS

Participant Descriptive Data Analyses

Analysis of the age data for the PD and control groups by a one-way ANOVA revealed no significant group differences. Separate Mann-Whitney U Tests were performed to compare ADL, Depression, and Mini-Mental State scores between the groups. A significant difference was found only for the depression score indicating that PD group had higher scores for depression than the control group ($p < .05$). Further review of the depression scores revealed that only 3 out of the 15 participants with PD were categorized as depressed on the Geriatric Depression Scale, whereas no participant in the control group attained a level of depression on the scale (Yesavage, et al., 1983).

Preliminary Analyses

Trial by trial, all tape recorded response onset and EMG signal data were transferred to the Biopac/AcqKnowledge data acquisition and analysis software for identification of response component times and EMG activity onsets. Prior to analysis, each trial's raw EMG measure of biceps muscle activity was centered about a zero baseline, fully rectified and smoothed (10 points), and EMG onsets indicated by an algorithm of three standard deviations above the baseline mean. The baseline mean was measured across a .5 s time interval of EMG activity prior to the visually-identified deflection of the EMG signal from the baseline. The time intervals for premotor time, RT, and total response time were identified and recorded from switch onset recordings. Motor time was calculated by subtracting premotor time from RT, and movement time was calculated by subtracting RT from the total response time.

Participant means for each dependent variable: RT, premotor, motor, movement, and total response time were calculated for 20 trials of each condition. Values two standard deviations above or below each subject's mean were removed from the data set (Ratcliff, 1993), then the means were re-calculated. One subject was eliminated from the group with PD because of an insufficient number of adequate test trials. This individual's age- and gender-matched control subject without PD was subsequently removed from the study as well. The descriptive data are reported by group for each dependent variable: RT, premotor, motor, movement, and total response time in Tables 3, 4, 5, and 6, respectively.

Movement Complexity and Practice

Separate 2 x 2 x 3 (Group x Complexity x Test Session) mixed design ANOVAs were performed for the following variable means: premotor time, RT, motor time, and movement time. Tukey's Honestly Significant Difference (HSD) post-hoc analysis further differentiated the variable means for significant interactions.

Reaction Time

Analysis of the RT data revealed a significant Complexity x Test Session interaction, $F(2, 56) = 7.36$, $p < .05$. Figure 5 illustrates the overall RT interaction. Post-hoc analysis determined that the overall RT mean for the simple movements (305 ms) was significantly different than for the complex movement (346 ms) . The mean RTs for both simple and complex movements for the immediate retention test decreased significantly from the pretest values, but the difference between RT simple movement and complex movements for the immediate retention test was not significant (simple, 137 ms and complex, 142 ms). The delayed retention test RT means for both simple and complex movements were not significantly different from the immediate retention values .

These findings indicate that both the PD and control groups exhibited a movement complexity effect for RT, noting that the mean RT for the complex movement was significantly greater than the mean RT for the simple movement. With practice of each movement (120 trials each on Day 1 and Day 2), followed by a 10 minute rest period and immediate retention test, both groups improved significantly in RTs for both the simple and complex movements. The movement complexity effect for RT diminished with practice across the two days, such that the RT for the complex movement became equal to that of the simple movement. This relationship was sustained across a 48 hour rest interval as indicated by the delayed retention test. These data demonstrate that participants with PD and those without PD respond to practice in the same way.

Premotor time. A significant Complexity x Test Session interaction was also revealed for premotor times, $F\ (2, 56) = 6.65, p < .05$. The interaction is displayed in Figure 6. Similarly, for both the PD group and the group without PD, the difference between mean premotor times for the simple and complex movements were significant only for the pretest session (175 ms and 203 ms). These premotor values decreased significantly at the immediate retention test (137 ms and 142 ms) and were maintained across the delayed retention test (136 ms and 144 ms).

The premotor times mirror those of RT for the movement complexity effect. In the pretest, the simple movement premotor values were significantly different than those for the complex movement. With practice, however, this effect is eliminated and remains stable for both immediate retention and delayed retention intervals.

Motor time. A third significant interaction was found in the motor time analysis, a Group x Test Session interaction, $F\ (2, 56) = 5.79, p < .05$. The interaction is shown in Figure 7. The post-hoc analysis of the Group x Test Session interaction ascertained that for the pretest, the group with PD had significantly slower motor times than the control group. From the pretest to the immediate retention test, motor times decreased by 33 ms for the group with PD and no changes were found for the group without PD. The improvement in motor times for the PD group was sustained across the delayed retention test interval.

Movement Time

The 2 x 3 x 3 (Group x Complexity x Test Session) analysis of mean movement times indicated a significant Complexity x Test Session interaction, F (2, 56) = 94.07, $p < .05$. Figure 8 illustrates the interaction. Post-hoc comparisons demonstrated that overall the movement time means for the complex task were greater than those for the simple task (movement between two response switches). Across the practice training, significantly faster movement times were identified only for the complex movement. The values for complex movement times changed from the pretest to the immediate retention test (1.27 s to 901 ms). These faster movement times were sustained between the immediate and delayed retention tests. These results indicate that individuals with PD, as well as those without PD, became significantly faster in movement times for the complex task, but no significant change was observed for the movement times in the simple task. Furthermore, both groups maintained the improved movement time performance in the complex task when tested for delayed retention 48 hours later.

A second movement time interaction, Group x Complexity interaction for movement times approached significance, F (1, 28) = 3.79, $p = .06$. The group with PD had longer movement times only for the complex movement than the group without PD (1.11 s and 941 ms).

Summary

To summarize, for both groups with and without PD, differences between simple and complex movement RT, premotor, motor, and movement times were found in the pretest. The two groups responded similarly to two days of practice, demonstrating significant improvements in the complex movement premotor, motor, and RTs from the pretest to the immediate retention test. These improvements eliminated the significant difference between the simple and complex movement for these variables and thus the complexity effect. Practice improvements were maintained from the immediate to the delayed retention test, indicating that the observed effects were a result of learning. For the pretest, the motor times of the group with PD were significantly slower than the control group, however they also decreased with practice, thus canceling the group differences in the immediate and delayed retention tests. The improvements in motor times by the group with PD remained stable at the delayed retention test.

For the PD group, the faster RTs observed after practice were a result of decreases in both premotor and motor times. In contrast, the group without PD developed significant faster RTs with practice only by significant decreases in premotor times.

Overall, the MTs for the complex task were greater than the MTs for the simple task. With two days of practice, however, both groups improved their MTs for only the complex task. These improvements remained across the 48 hour interval. Practice had a uniformly greater effect on improving the MTs of the complex task than those of the simple task.

With practice, both groups with and without PD improved RT, premotor, and MTs from the pretest to the immediate retention test and maintained their level of performance through delayed retention testing. Persons with PD also demonstrated the identical pattern of improvement in motor times across the same practice and testing intervals. These results indicated that both individuals with PD and those without PD demonstrated similar motor learning effects for RT, premotor, and movement times. The PD group alone demonstrated a learning effect for motor times.

Transfer

The initial BBT scores for two participants were not recorded. The descriptive data for the BBT scores is presented in Table 7. Analyses were performed excluding BBT scores for these two participants and their matched controls. A 2 x 2 (Group x Test Session) mixed design ANOVA for the Box and Block Test scores (BBT) revealed a significant Group effect, F (1, 24) = 5.73, $p < .05$. The mean BBT score for participants with PD was significantly lower (56 blocks) than for participants without PD (66 blocks), as seen in Figure 9. Thus, persons with PD were significantly slower than persons without PD when performing a timed task requiring repetitive grasping of 2.54 cm cubes, transporting it across a partition, and releasing into a box. A Test Session effect approached significance, $\underline{F}$ (1, 24) = 4.25, $\underline{p} = .0503$ with BBT scores increasing from 60 to 62 blocks.

Pearson product moment correlations comparing BBT scores for Day 1 with Day 2 for each of the groups determined significant, positive correlations (.98 and .88, $\underline{p} < .05$). Thus, after both groups practiced simple and complex, rapid arm-reaching movements across two days, there was a significant association in BBT performance from Day 1 to Day 2.

In addition, Pearson product moment correlations were conducted examining the relationships between BBT Day 1 scores and pretest complex movement means for RT and movement time between BBT Day 2 scores and the same dependent variables, and between Day 1 and Day 2 scores. A significant correlation was determined only for the comparison of BBT Day 1 and Day 2 scores (.94, $\underline{p} < .05$). Thus, performance of the rapid, arm-reaching movements required for the complex task were not associated with the BBT scores.

Pearson product moment correlations were further performed separately for the groups with and without PD. The results of this correlational analysis are interpreted cautiously as less than 30 paired comparisons formed the data set (Morehouse & Stull, 1975). First, the relationships between BBT Day 1 scores and the pretest complex movement means for RT and movement time were examined. Second, the associations between BBT Day 2 scores and the immediate retention test, complex movement means for RT and movement time were tested. Two significant correlations ($\underline{p} < .05$) were found only for the control group: (1) for Day 1, a correlation of -.54 for reaction time and BBT scores and (2) for Day 2, a correlation of -.68 for movement time and BBT scores. These findings indicate that on Day 1 persons without PD demonstrated faster RTs for complex movements associated with higher BBT pretest scores. On Day 2, persons without PD performed faster movements relative to higher BBT scores.

Resolution of Hypotheses

Movement Complexity Hypotheses

When compared to the control participants, the participants with PD will have significantly slower: (1) overall simple RTs, (2) premotor times, (3) motor times, and (4) movement times. From the findings of this study, participants with PD had significantly slower motor times than the controls and otherwise demonstrated no significant differences for RTs, premotor times, and movement times. A trend was observed in the data as movement time differences approached significance for the two groups.

When comparing RTs for a simple to more complex movement, control participants will demonstrate a significant increase in (1) overall RTs and (2) premotor times. The analysis of this study indicated that both participants with and without PD demonstrated a significant increase in (1) overall RTs and (2) premotor times.

For the RT changes for a simple to more complex movement, participants with PD will demonstrate less change in (1) overall RTs and (2) premotor times than matched controls, thus demonstrating deficit behavior. The results indicated that participants with and without PD demonstrated equivalent performance change in (1) overall RTs and (2) premotor times.

Practice Hypotheses

Participants with and without PD will benefit significantly from practice for: (1) premotor times, (2) overall RTs, and (3) movement times. This hypothesis was upheld with both groups demonstrating improvement in each of these variables with two days of practice (120 trials for each task).

Participants with PD will benefit significantly less from practice than control participants for: (1) premotor times, (2) overall RTs, and (3) movement times. The means for each of these variables will decrease more for complex movements than for simple movements for both groups. The first component of this hypothesis was not supported in that both groups benefited equally from practice. The second component was supported with the means of each variable decreasing more for complex movements than for simple movements for both groups.

Transfer of Skill Acquisition Hypotheses

(1) Participants with and without PD will improve on the transfer task scores of the BBT from pretest to posttest. The data did not support this hypothesis, though a trend towards significance in the right direction was reported.

(2) Participants with PD will score significantly lower on the BBT compared to matched controls for both pretest and posttests. This hypothesis was supported by the findings.

(3) Participants who demonstrate faster RTs and MTs on the two tasks of varying complexity will demonstrate higher BBT scores. Analysis of the combined groups did not support the hypothesized association for arm-reaching RTs, MTs, and BBT scores. Analysis of the groups separately supported an association for RT and MT for only the group without PD.

(4) Significant improvements in BBT scores will be displayed by participants with decreased RT and MT scores from pretest to posttest.. This hypothesis was not supported as both groups overall demonstrated decreases in RT and MT scores, but neither improved in the BBT from Day 1 to Day 2.

Coefficient of Variation Scores as a Measure of Response Consistency

Coefficients of variation were calculated from the adjusted data sets for each dependent variable means. The CV was selected as a measure of response consistency because it is a measure of relative variation. This measure accounts for differences in the magnitude of the means by representing the standard deviation as a proportion of the mean (Portney & Watkins, 1993). Mean CV are reported for each dependent variable in Appendix H. Separate 2 x 2 x 3 (Group x Complexity x Test Session) mixed design ANOVAs were performed for the coefficients of variation (CV) of RT, premotor time, motor time, and movement time. Tukey's HSD post-hoc analysis was performed to further assess significant interactions.

Reaction Time

Analysis of the RT mean CV indicated a significant Test Session effect, F (2, 56) = 12.01, $p < .05$ (Appendix I). Thus, both of the groups demonstrated a similar pattern of change in RT variability. Post-hoc analysis determined that RT variability decreased significantly from the pretest to immediate retention test and was maintained through the delayed retention test. These findings complement the results of the mean RT analysis in that both groups behaved similarly across test sessions. Both groups demonstrated improved RTs and decreased variability of responses from pretest to immediate retention and sustained those improvements at the delayed retention test.

Premotor time. A significant Group x Complexity x Test Session interaction was revealed from analysis of the premotor time mean CV, F (2, 56) = 3.75, $p < .05$, (Appendix I). Comparison of the means found that both the group with and without PD decreased premotor time variability for the complex movement from the pretest to the immediate retention test and held the decrease stable through the delayed retention test. Initially, premotor time variability for the two groups did not differ, however, the immediate retention test CVs were significantly less for the group without PD than the control group. This difference was alleviated at the delayed retention test.

Regarding the simple movement task, only the group with PD demonstrated a decrease in the CV from pretest to immediate retention test, but did not maintain the decrease with delayed retention testing. The CV for premotor times of the group without PD decreased significantly from the pretest to delayed retention testing. A significant difference between the CV means of the two groups was found only for the delayed retention test.

Overall, the premotor time variability parallels the premotor time mean changes for both groups across training noting improvements in both measures. Also, the initial measures of variability were not significantly different for the two groups across movements of varying complexity, yet the control group demonstrated the greatest decrease in variability for both arm-reaching movements.

Motor time. A significant Group effect, F (1, 28) = 7.29, p > .05, identified overall a more variable motor time for persons with PD than the group without PD (mean CV, .22 and .16, respectively). See Appendix I. Though the mean motor times of persons with PD decreased across test sessions, the variability in motor times for these individuals remained greater than that of persons without PD across testing sessions.

Movement Time

A significant Complexity x Test Session interaction was found for movement time CV, F (2, 56) = 3.86, p > .05, Appendix I. Post-hoc comparisons revealed that across test sessions, movement time variability for the simple arm-reaching task was greater than that for the complex arm-reaching task. In addition, movement time variability decreased for the complex movement from pretest to immediate retention relative to minor increases in variability of simple movement. Second, a significant Group x Test Session interaction was revealed for movement time CV, F (2, 56) = 5.19, p > .05, (Appendix I). Tukey's post-hoc analysis demonstrated that pretest movement time variability was greater for the group with PD and decreased to a level comparable to the group without PD.

Summary

Both the group with and without PD demonstrated similar values for response variability across the testing sessions for RT and premotor times. Both groups also demonstrated equivalent decreases in response variability across the test sessions for RT and premotor times. At the pretest, persons with PD demonstrated significantly greater variability for motor and movement times. Motor time variability for persons with PD decreased across test sessions but remained greater than the variability for the control group. In contrast, movement time variability for persons with PD decreased to a level comparable to the control group. For both PD and control groups, movement time variability was greater for the simple arm-reaching task than the complex arm-reaching task.

Table 3. Descriptive Data for Mean Reaction Time (ms) for Simple and Complex Arm-reaching Tasks for Groups: Parkinson's Disease and Control

	Simple Arm-reaching Task						Complex Arm-reaching Task					
	Pretest		Imme Retention		Del Retention		Pretest		Imme Retention		Del Retention	
RT	PD	Control	PD	Control	PD	Control	PD	Control	PD	Control	PD	Control
Mean	314	297	255	241	250	236	354	337	267	248	262	253
SD	64	38	39	29	40	31	67	59	43	39	40	44
Range	220 - 446	243 - 374	173 - 314	191 - 286	175 - 328	192 - 300	264 - 530	243 - 476	192 - 319	191 - 317	196 - 333	187 - 322

Note. RT = reaction time; SD = standard deviation; PD = Parkinson's disease; Imme Retention = immediate retention; Del Retention = delayed retention.

Table 4. Descriptive Data for Mean Premotor Time (ms) for Simple and Complex Arm-reaching Tasks for Groups: Parkinson's Disease and Control

	Simple Arm-reaching Task						Complex Arm-reaching Task					
	Pretest		Imme Retention		Del Retention		Pretest		Imme Retention		Del Retention	
PreTime	PD	Control	PD	Control	PD	Control	PD	Control	PD	Control	PD	Control
Mean	172	178	140	133	137	136	195	211	144	140	137	151
SD	53	28	36	24	33	17	61	49	35	22	38	24
Range	103 - 305	135 - 235	90 - 208	88 - 174	96 - 206	111 - 160	113 - 378	132 - 315	98 - 208	102 - 168	94 - 220	110 - 195

Note. PreTime = premotor time; SD = standard deviation; PD = Parkinson's disease; Imme Retention = immediate retention; Del Retention = delayed retention.

Table 5. Descriptive Data for Mean Motor Time (ms) for Simple and Complex Arm-reaching Tasks for Groups: Parkinson's Disease and Control

	Simple Arm-reaching Task						Complex Arm-reaching Task					
	Pretest		Imme Retention		Del Retention		Pretest		Imme Retention		Del Retention	
MotorT	PD	Control	PD	Control	PD	Control	PD	Control	PD	Control	PD	Control
Mean	139	114	112	108	111	98	156	124	119	105	119	101
SD	34	24	27	18	32	20	38	29	28	24	34	26
Range	95 - 193	69 - 152	73 - 189	70 - 144	67 - 179	66 - 136	93 - 226	87 - 185	73 - 168	70 - 164	76 - 179	56 - 162

Note. MotorT = motor time; SD = standard deviation; PD = Parkinson's disease; Imme Retention = immediate retention; Del Retention = delayed retention.

Table 6. Descriptive Data for Mean Movement Time (ms) for Simple and Complex Arm-reaching Tasks for Groups: Parkinson's Disease and Control

	Simple Arm-reaching Task						Complex Arm-reaching Task					
	Pretest		Imme Retention		Del Retention		Pretest		Imme Retention		Del Retention	
MT	PD	Control	PD	Control	PD	Control	PD	Control	PD	Control	PD	Control
Mean	200	183	130	106	134	111	1376	1169	972	831	949	820
SD	74	68	32	38	35	41	377	279	233	131	230	134
Range	103 - 368	79 - 350	84 - 195	45 - 195	76 - 197	33 - 194	918 - 2127	708 - 1804	624 - 1474	573 - 1060	654 - 1398	543 - 1034

Note. MT = movement time; SD = standard deviation; PD = Parkinson's disease; Imme Retention = immediate retention; Del Retention = delayed retention.

Table 7.

Descriptive Data for the Box and Block Test (BBT) scores for Day 1 and Day 2 by Group: Parkinson's Disease and Control.

	Group					
	Parkinson's Disease			Control		
# Blocks	Mean	SD	Range	Mean	SD	Range
Day 1	56	11	38 - 74	64	12	40 - 80
Day 2	56	10	41 - 74	68	11	45 - 84

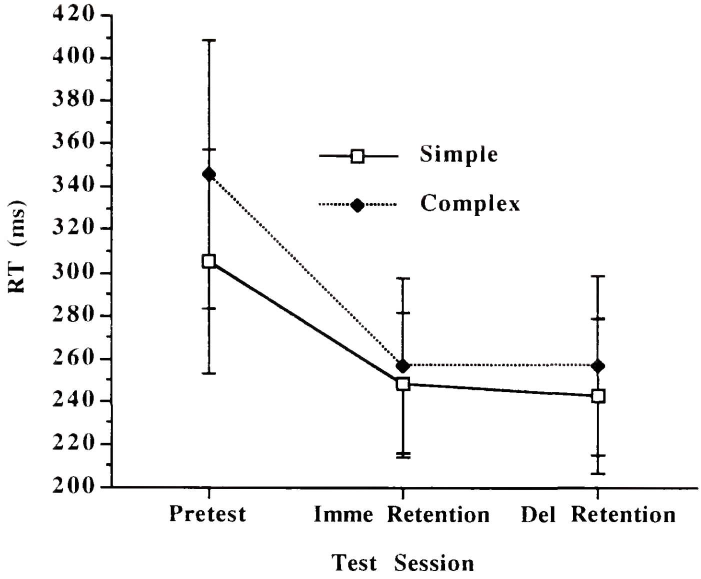

Figure 5. Reaction time means and standard deviations for complexity x test session interaction. Imme = immediate. Del = delayed.

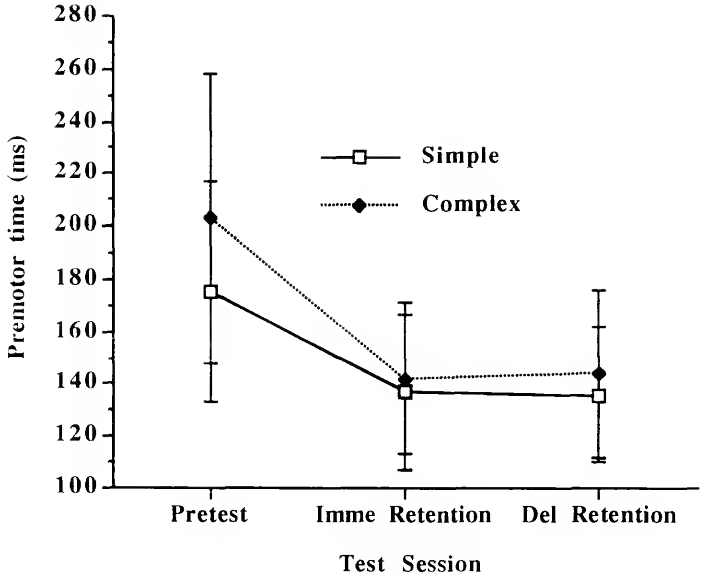

Figure 6. Premotor time means and standard deviations for complexity x test session interaction. Imme = immediate. Del = delayed.

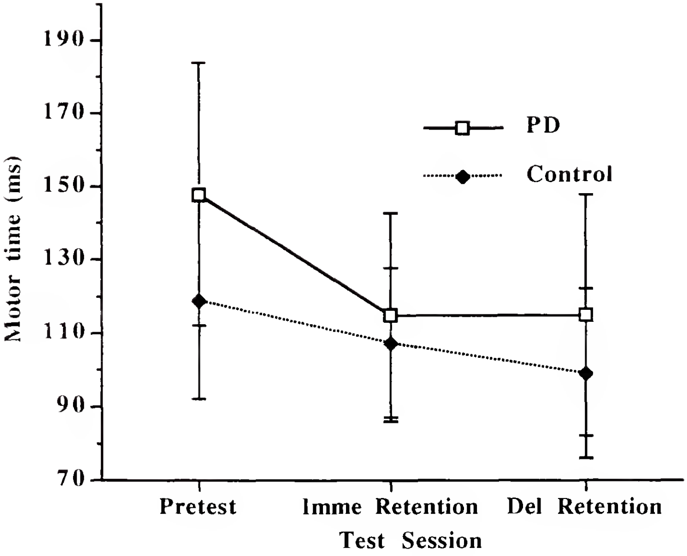

Figure 7. Motor time means and standard deviations for group x test session interaction. Imme = immediate. Del = delayed.

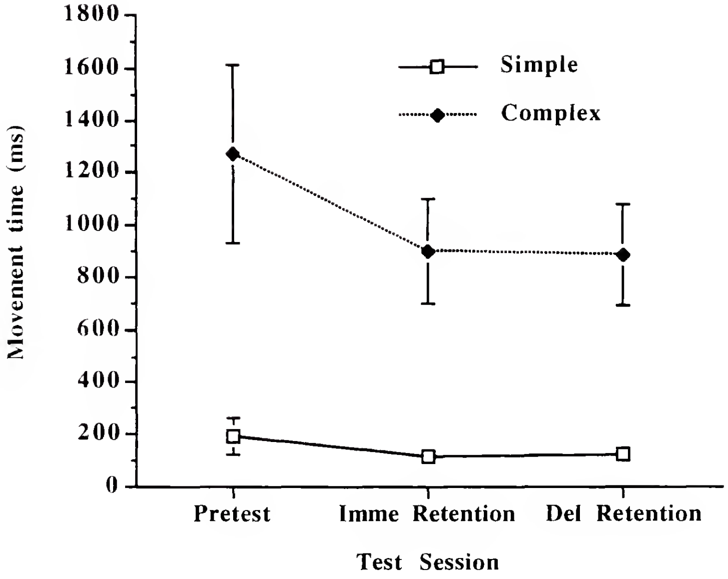

Figure 8. Movement time means and standard deviations for complexity x test session interaction. Imme = immediate. Del = delayed.

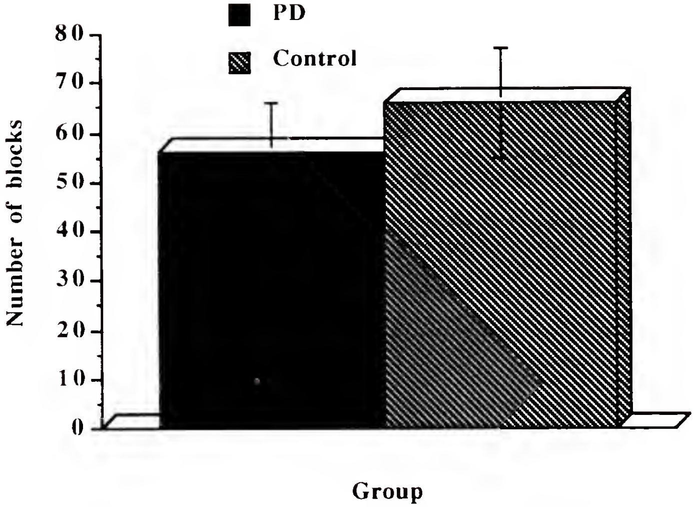

Figure 9. Mean number of blocks and standard deviations for Box and Block Test group effect.

CHAPTER 5
DISCUSSION, SUMMARY, CONCLUSIONS, AND IMPLICATIONS FOR FUTURE RESEARCH

This study was designed to (1) examine the effects of PD and movement complexity on response programming, (2) determine the differential effects of practice on altering response programming in persons with and without PD, and (3) examine transfer of the practice effect for fast arm-reaching movements to another upper limb motor skill. The discussion of the results follows the same order to address the three investigated areas.

Discussion

Parkinson's disease results in a spectrum of movement difficulties including slowed initiation and execution of movements, movement arrest, resting tremor, postural changes, and an absence of associated, automatic movements. Delay in initiating movements, termed akinesia, is one of the distinct movement problems associated with PD. Controversy prevails in the literature concerning the occurrence and cause of akinesia (Evarts, 1980; Montgomery, Gorman, & Nuessen, 1991; Zappia, Montesanti, Colao, & Quattrone, 1994). Several researchers have reported deficits in the response programming stage of information processing by persons with PD and have associated this deficit with movement or response initiation delays (Harrington and Haaland, 1991; Stelmach et al., 1987).

Response programming is the transformation of a selected, cognitive response code to a motor response code as execution commands for the task. RT latency has been used as a measure of programming time with the perspective that greater central nervous system preparation time is required to coordinate and organize more complex movements. The movement complexity effect is a statistically significant increase in RT as a result of specifically increasing the complexity of a movement (Light & Spirduso, 1990). Older adults are particularly sensitive to task complexity resulting in age-related slowing for RTs (Fozard, Vercruyssen, Reynolds, Hancock, & Quilter, 1994). The effects of PD on response programming and RTs must be differentiated from the effects of healthy aging on RTs. For this study, two levels of movement complexity were manipulated by the number of steps in a movement sequence (one to four) and number of directional changes in the movement (zero to three) (Christina, 1992; Light, Reilly, Behrman, & Spirduso, in press).

RT latency can be fractionated by the demarcation of EMG activity onset into its subcomponents of premotor time and motor time. From this division, the contribution of central neural processing time (premotor time) can be distinguished from that of peripheral processing time (motor time). In examining the basis for RT delays in persons with PD, the delineation of premotor time from motor time provides a more sensitive and descriptive means of RT analysis.

In this study, initial RT latencies of the PD group were not significantly different from those of the control group. However, both groups demonstrated a movement complexity effect for RT responses for the arm-reaching tasks of varying complexity. Thus, the more complex movement took a greater time to prepare than the simple movement. The significant difference in RTs between the two tasks verified that the tasks represented two distinct levels of movement complexity. Examination of the fractionated components of RT between the two tasks revealed that RT differences were specifically due to longer premotor times for the more complex movement compared to the premotor times for the simple movement. Because no differences were found for motor times between the simple and complex task, the movement complexity effect on RT latencies can be conclusively attributed to the premotor time component. Longer premotor times signify that greater central neural processing time was required to prepare the complex movement in comparison to the simple movement.

Effect of PD on Response Programming and Movement Time

Reaction Time

In the present study, the lack of a significant difference between RTs of the PD and control groups, as well as similar group responses to complexity was unexpected and adds to the controversy surrounding RT, akinesia, and PD. The contradictions and inconsistencies concerning the relationship between RT and PD have stimulated research aimed at discerning their cause(s). Inconsistent findings have been attributed to differences among study samples, the true variability in the PD population, duration of PD, age of onset of PD, severity of PD, medications, extremity affected, and types of experimental tasks (Evarts, 1980; Montgomery et al., 1991; Rogers & Chan, 1988; Ruberg, Scherman, Jovoy-Agid, & Agid, 1995).

In Table 8 the type of experimental task, mean age of participants, and mean RT for persons in the present study are compared to those found in the literature on PD, simple RTs, and response programming. As can be seen in Table 8, the PD group RTs for the current study appear to be somewhat faster than those reported in the literature and that the results of the present study are most similar to those of Rogers and Chan (1988). Significant differences were not found in either study for mean simple RTs between groups with and without PD. The experimental tasks and test conditions for these two studies are alike in that both tested rapid flexion responses to a predictable environmental cue, though Rogers and Chan (1988) tested the lower extremity and the current researcher tested the upper extremity. These experimental similarities may account for the comparable findings for these two studies. However, researchers testing other types of tasks have observed group differences for mean RTs between persons with and without PD.

In the current study, the equivalent RT performances for the PD and control group was an exceptional finding relative to the quantity of literature supporting group differences. In the next section, the validity of this finding and possible explanations for this outcome will be addressed. Following this discussion, the significance of the similar findings for response programming between the PD and control groups will be considered.

Group similarity. The lack of significant RT differences between the participants with and without PD could be accounted for in a variety of ways. Possibly the current experimental design failed to have adequate power and therefore resulted in a beta error. A lack of power may result from too few participants relative to the standard deviation of the response variable, the size of the value designated as meaningful and significant, and the significance level set for the study (Marks, 1982; Portney & Watkins, 1993). Recalculation of the power analysis to determine the appropriate number of participants needed for this study indicated that the 15 participant sample size per group was adequate. Specifically, the RT standard deviation determined from this study's results did not exceed the standard deviation used for the initial power analysis. The recalculation of power for this study demonstrates that the RT data are representative of the true population mean. Other factors which may have influenced the RT data outcome will be considered next.

Researchers have recognized that variability in the PD population may account for discrepancies among RT studies. In this study, RT variability in persons with PD is a possible explanation for the equivocal performance by the PD and control groups. For the current study, the coefficient of variation (CV) was selected as a measure of response variability. The CV accounts for variations in the magnitude of the mean by representing the standard deviation as a proportion of the mean (Portney & Watkins, 1993). The CV for persons with PD has varied in the literature from a value of .33 (Stelmach et al.; 1992) to a value of .09 (Rogers & Chan, 1988). The sample size for each of these studies was limited to seven individuals with PD. In comparison, the CV for the PD group in the current study of .19 for the complex task and .17 for the simple task (Table 11) appears to be in the middle of the range of variability. Only Stelmach et al. (1992) reported significant group differences for the CV. However, in the current study, overall variability decreased significantly from the pretest to the immediate retention test and was maintained through the delayed retention test. Variability of performance, as measured by CV, does not provide a plausible explanation for the RT outcome in this study as compared to other studies (Evarts et al., 1981). The relatively greater amount of response consistency found in the current study, however, warrants further consideration in future investigations.

Other potential explanations for equivalent RTs for the PD and control groups include the participant's degree of motivation and the influence of depression on motivation. No objective measurement of motivation was not attempted in the current study. However, the offering of a financial incentive may have affected subject motivation. Other reports in the literature concerning PD and RT did not report such incentives. Motivation and performance may be influenced by both intrinsic and extrinsic factors and achievement goals (Duda, 1993; Roberts, 1993). Each participant knew that they would receive monetary compensation ($50.00) for completing the study, as well as a report of their individual performance compared to the outcomes for both the PD and control group. An additional bonus of $50.00 was awarded to the participant demonstrating the fastest average response time on Day 3 for each PD and control group. The effects of the monetary compensation, bonus, and performance information on participant motivation and performance may have varied according to individual perceptions of rewards, incentives, and achievement goals. Several participants with PD subjectively commented that at their age money was not a strong incentive and that their particular interest in participating was to see how they performed and how they compared to individuals without PD. These subjective comments by the participants concerning the effect of monetary reward on performance are supported in the literature (Grant, Storandt, & Botwinick, 1978). As motivation was not directly assessed in this study, its effect on the findings can only be speculated from experimenter casual observation and participants' comments.

An indirect measure of motivation is persistence in task performance (Duda, 1993). Both groups attended all three practice and testing sessions and thus persisted in performance across the three days achieving a 100 per cent attendance. Another indirect index of participant motivation or potential for motivation is an objective evaluation for depression. Individuals with depression may not attend, concentrate, or persist in learning a new task as well as individuals who are not depressed. These differences in participation and motivation may be reflected in lower performance scores for individuals who are depressed. The RT results of studies reporting differences in depression scores between the groups may have been influenced by the effect of depression on motivation and performance (Harrington & Haaland, 1991). In the current study, a significant difference for the mean depression score was observed between the two groups. If depression had influenced performance outcome, slower RTs would be expected, as opposed to faster RTs. The arm-reaching response scores for the three individuals with PD and depression are in the similar range as the timed responses of the other PD participants. Depressive states did not appear to influence the scores negatively and is thus ruled out as associated with the lack of RT differences between the PD and control groups.

A third possible factor that could have influenced the RT results in this study were the levels of medication in persons with and without PD. A review of the medication list reported by each participant found no medications listed affecting RT (Barnhart, 1988). Participants with PD were tested during an on-medication period for treatment of PD and at the same time during the medication cycle for each of the test sessions. In this study, 13 participants were being treated with sinemet for PD and 7 participants were treated with eldepryl in combination with sinemet. No subject reported a change in their medication schedule or a change in their physical status from one test session to the next.

Pharmacological intervention for PD has been successful in treating bradykinesia, rigidity, and tremor. Beneficial RT effects of medication, in particular L-dopa, have not been confirmed to the same degree in the literature (Cutson, Laub, & Schenkman, 1995). An exception is a study by Pullman et al. (1988) in which the researchers reported a lack of dosage concentration effect on simple RT, yet an increase in choice-RT as plasma L-dopa levels decreased. These researchers proposed that the differential effect of dosage on simple and choice-RT was due to different neural circuitry involved in the two tasks. Simple RT may be partially dependent on nondopaminergic paths, such as arousal systems. Choice RT, however, may be highly dependent on higher level cortical processing necessary for cognitive and complex motor behavior. A parallel may be suggested for the effects of L-dopa comparing Pullman et al.'s study and this study examining simple RT for simple and complex tasks. All movements in the current study were examined for simple RTs with no significant differences found between the PD and control groups. Response complexity can be altered by manipulating any stage of information processing. One method could be varying the number of response choices (simple vs. choice-RT) and another varying the degree of movement complexity. Both manipulations affect response complexity by affecting separate and distinct stages of information processing: response selection and response programming, respectively. The effects of medication on choice-RT and movement complexity should thus not be equated.

According to Montgomery et al. (1991), the finding of high RT variability, yet high MT consistency across studies with different samples of individuals with PD may be attributed to a division of labor for motor initiation and motor execution. This division of labor is delineated both anatomically and physiologically between the caudate nucleus for motor initiation and putamen circuits for execution, respectively. Montgomery et al. (1991) cited greater variability in dopamine loss in the caudate compared to the putamen as a rationale for the variability in RT performance in persons with PD across studies. Such variability across studies may account for overall RT differences observed in this sample of persons with PD when compared to previous studies.

If variability in the loss of dopaminergic innervation (Kish, Shannak, & Hornykiewicz, 1988) accounts for the variability in RT performance, are such differences associated with age at PD onset or with duration of the disease? Ruberg et al. (1995) found that the loss of dopaminergic innervation in the striatum of patients with PD was not affected by age of onset but only by disease duration. According to Ruberg et al., an individual with a 1 year duration of PD is less likely to have the same amount of dopaminergic loss as an individual with a 15 year duration of PD. In the current study, the individuals with PD varied in disease duration from 1 to 15 years. These duration differences may have contributed to the lack of differences in RT between PD and control groups. To test this possibility, the responses for the participant with a 1 year history of PD were compared to the overall group mean. The RT values for the individual with a 1 year duration were within 2 standard deviations of the group mean, therefore duration of PD did not appear to be an influential factor in the RT data.

Lastly, Evarts (1981) and Rafal, Friedman, and Clannon (1989) documented faster RTs for the lesser involved limb in persons with PD compared to the more involved limb. In the current study, 4 of the 15 participants with PD reported that their left arm was more involved than their right arm. As all participants performed the arm-reaching tasks with their right arm, the RTs for the 4 individuals with greater left side impairment may have been slower if testing had been performed with this limb. Comparison of the RT values for these 4 individuals with the group mean confirmed that their scores were within 2 standard deviations of the mean and thus did not seem to affect the data as outliers.

From this examination of the RT data in comparison to previous studies and for potential influential variables, no definitive conclusion can be made to justify the lack of RT differences between the PD and control groups. Researchers have reported both RT differences and no differences between persons with and without PD (Pullman et al., 1988, Rogers & Chan, 1988). Task differences and practice conditions among studies could explain the discrepancies between the current study's findings and the literature. In the current study, similar group responses were observed for RTs, as well as similar group effects to movement complexity.

Movement complexity effect: Reaction time. For the pretest, a movement complexity effect for RTs of the control group was expected and consistent with the previous literature (Light & Spirduso, 1990; Light et al., in press). As the complexity of the movement increased, RTs increased significantly. Observing a similar movement complexity effect for the RTs of the PD group was not expected. In the following discussion, this finding will be compared with the results and conditions for previous response programming studies of persons with PD. The element(s) of movement complexity manipulated and the type of response task examined in these studies may be the discriminating factors for identifying the response programming deficits in persons with PD from the responses of healthy, age-matched persons.

In contrast to the results of the present study, Stelmach et al. (1987) determined that the RTs for only the control group performing a repetitive, rapid index finger-tapping task (1 to 5 taps) demonstrated a linear increase of RT with respect to increases in sequence length. Evidence for a programming deficit in persons with PD was further supported by an overall prolonged first intertap interval compared to the control group. According to Stelmach et al. (1987), this finding indicated that persons with PD responded to the first tap with similar RTs regardless of sequence length, followed by ongoing monitoring to produce the correct number of subsequent taps. A comparative analysis of the simple task MT and the first interswitch interval MT for the complex task was not conducted for this study, however, such an analysis may be a means to examine differences in programming execution between the groups. This analysis will be performed in the future to examine movement execution differences between persons with and without PD.

Harrington and Haaland's outcomes (1991) were similar to those of Stelmach et al. (1987). Their findings supported the view that persons with PD have a deficit in response programming influenced by response complexity and sequence length. These researchers found significant RT differences between persons with PD and a control group performing repetitions of different, functional hand postures varied by sequence length (1 to 5). The PD group was less influenced by sequence length for the different hand postures than the control group. In contrast, both groups demonstrated a movement complexity effect for sequences of identical hand postures. The hand postures included pressing a button, hitting a lever, and grasping a handle.

Comparing the results of studies on PD and response programming provides an interesting background for the results of the current study. Harrington and Haaland (1991) determined a complexity effect for identical repetitive hand postures in persons with PD, whereas Stelmach et al. (1987) did not find a complexity effect for identical, repetitive finger-tapping in the PD group. Response programming deficits in the PD population were apparent to Stelmach et al. (1987) for all levels of the task studied. Harrington and Haaland (1991) did not observe programming deficits until the sequence of the task response was varied by changing the functional hand postures as opposed to requiring the same hand postures in repetition. From a theoretical perspective, discrepancies such as these in the literature are difficult to explain . If persons with PD are as sensitive to complexity changes manipulated by sequence length as demonstrated by Stelmach et. al. (1987), one would anticipate similar findings for the repetitions involving identical, hand postures. Based on the number of digits and proximal stabilization required to perform the two tasks, repetitive finger movements appear less complex than repetitive identical hand postures. However, a response programming deficit was found for persons with PD dependent on sequence length for a simple finger-tapping task but not for the more complex task of repetitive identical hand postures. Harrington and Haaland (1991) found further that a difference in response programming performance between persons with and without PD dependent not only on response sequence length, but also on the movement complexity issue of different versus same hand posture in sequence.

The findings by Jones et al. (1994) also demonstrated programming deficits in persons with PD compared to a control group for the advanced preparation of button-pressing sequences. The control group demonstrated greater response preparation time for sequences of three or more presses, whereas the PD group RTs were not affected by change in sequence length. In the Jones et al. study, persons with PD did not exhibit a movement complexity effect for sequence length, whereas the findings for the current study demonstrated similar group responses to movement complexity defined by sequence length and the number of directional changes. In addition to task differences, the combination of directional change and sequence length may have had a different effect on response programming in the current study than sequence length alone.

Similar to the findings of the current study, Rafal et al. (1987) found no differences in the response programming effects on simple RTs for persons with PD performing finger press sequences of 1 to 3 parts compared to control groups. Thus, similar movement complexity effects on RT were determined for the PD and control groups. A methodological discrepancy between the Rafal et al.(1987) study and the present study is that Rafal et al. averaged the RTs for the right and left limbs. Averaging limb RTs may have masked differences between the PD and control groups due to variations between limb RTs for persons with PD (Evarts, 1980). Furthermore, Rafal et al. (1987) did not specifically age- and gender- match the control group to the PD group. For example, an age pairing was included with an age discrepancy of 8 years. In addition, the gender ratio was 5 males and 3 females for the PD group, whereas the paired controls included 2 males and 6 females. Since RTs are slower with increasing age and males have faster RTs than females (Spirduso, 1995), the group differences for age and gender may have affected the RTs in the Rafal et al. study . In comparison, typical age pairings in the current study were 2 years or less with identical and complete gender-matching of control participants to participants with PD.

The evidence for response programming deficits in persons with PD, as measured by RT latency, is inconsistent based on a comparison of the four studies just reviewed and the current study. Findings for a movement complexity effect in persons with PD are inconclusive and contradictory relative to the sequence length effect across studies and response tasks. Those studies in which RT did not differ between the PD and control groups may have reflected the amount of movement complexity in the tasks. If the extent or type of movement complexity was not adequate to generate response programming differences, similar RTs for persons with and without PD may have resulted (Jones et al., 1994; Rogers, 1991).

Though a movement complexity effect was found in the current study, the amount or type of complexity in the two arm-reaching tasks in this study may not have been adequate to differentiate the response programming problem of persons with PD from the control group. The types of complexity manipulated in the various studies reviewed may also be relevant to the response programming performance. The complex arm-reaching task in the current study can be described as an aiming task with four targets of identical size and force production requirement. The more complex movement entailed a movement sequence with three different amplitudes, three directional changes, and two different angles of directional change. Describing task differences based on amount and type of complexity may be pertinent to identifying the response programming deficits in persons with PD, especially when comparing studies and tasks.

Studies which demonstrated deficits in RTs between PD and control groups manipulated the type of complexity by varying sequence length for rapid index finger-tapping (Stelmach et al., 1987), repetitions of identical versus different hand postures (Harrington & Haaland, 1991), and button-pressing sequences in a series (Jones et al., 1994). Another type of movement complexity manipulation may be based on the task demands for the anatomy and musculature. For instance, complexity may vary according to the number of body sides, the number of joints, or perhaps the degree and sequencing of proximal to distal musculature required to perform the task (Light & Spirduso, 1990; Van Galen, Van Doorn, & Schomaker, 1990). The three studies noted here all entailed a distal limb requirement for finger manipulation. In the current study, relatively more proximal muscle control was required with a more gross movement of the hand and fingers to press the target switches. Programming demands may possibly be greater for motor tasks requiring finger manipulation compared to those that do not (Van Galen et al., 1990; van der Plaats & van Galen, 1990). If programming demands are greater for tasks involving finger manipulation, then differences in RTs between PD and control groups could be dependent upon the degree of finger control required. Examining this hypothesis is beyond the scope of the current study but it affords implications for future investigations.

Movement complexity effect: Premotor time. A complexity effect for premotor times has been reported previously for healthy individuals (Sheridan, 1984) and supports the concept of the movement complexity effect for RTs. The pattern of premotor findings for simple and complex movements in the current study was analogous to that for RTs for both PD and control groups. The longer premotor times observed for the more complex movement indicated the movement complexity effect for RTs for both groups. More central nervous preparation time was required to organize the complex movement compared to the simple movement. As with RT expectations, the investigator anticipated longer premotor times for the PD group than the control group. Though RTs have been reported to be longer in persons with PD, fractionation of RTs for tasks of varying complexity has been reported only once prior to the current study (Sheridan et al., 1987).

Sheridan et al. (1987), similar to the current researcher, examined response programming for persons with PD by manipulating movement complexity. Fractionated RT and MTs were dependent variables common to both studies. The two studies differed in that Sheridan et al., first, used an adaptation of the Fitts paradigm (1954) to manipulate target aiming complexity and second, compared choice-RTs to simple RTs. The present researcher examined only simple RTs. From this perspective, a comparison of the results of these two studies is pertinent and beneficial.

First, Sheridan et al. (1987) found that persons with PD had significantly longer premotor times than the control group for the simple RT condition, but that premotor times were not significantly different under the choice-RT condition. In contrast to Sheridan et al., the findings for the current study demonstrated that both PD and control groups had similar premotor times relative to variations of movement complexity under a simple RT condition. Sheridan et al. concluded that persons with PD had an impaired ability to use the advanced information provided in the simple RT condition to reduce the movement preparation time. Based on the current study, an alternative conclusion is made supporting similar response programming capabilities for persons with and without PD relative to the use of advanced information in a simple RT condition.

Stelmach and Worringham (1990) suggested that Sheridan et al.'s finding of longer premotor times for persons with PD may have been influenced by on-going learning of the psychomotor aspects of the task dynamics. As target aiming required a successful interaction between the participant , a lever, and a computer cursor, Stelmach and Worringham (1990) speculated that greater reliance on closed-loop feedback may have precluded the programming of this task in an open-loop manner. Target aiming in the current study was accomplished by the participant's own limb and did not require use of an intermediate instrument, such as a lever, for control. From this comparison, preprogramming may have occurred more easily for the direct limb aiming task.

Second, Sheridan et al. (1987) also observed no significant group differences for premotor times based on the manipulation of the index of difficulty for target aiming. From these findings, they suggested that the ability to construct a motor program is not impaired in persons with PD. Similarly, the current study determined that both PD and control groups demonstrated similar premotor times relative to variations of movement complexity. Sheridan et al.'s premotor findings for movement complexity in aiming tasks are similar to the movement complexity findings for the arm-reaching tasks of the current study. Sheridan et al.'s study and the current study indicated similar response programming capacities by persons with and without PD for rapid, aiming tasks of varying movement complexity or difficulty. Sheridan concluded further that the details of the motor program are preserved in PD.

Discrepancies among the findings of studies of persons with PD for fractionated RTs may be attributed to differences in the processing of EMG data and the procedure used to designate EMG onsets. Researchers have not clearly reported their procedures such that exact replication is possible (Stelmach et al., 1992; Sheridan et al. 1987). Furthermore, the procedures for EMG onset designation have differed in the literature on EMG analysis from the use of visual observation to the use of a standardized algorithm (Turker, 1993, Walter, 1984). Moreover, researchers have reported that the surface EMG signal of persons with PD has a lower amplitude with inconsistent discharge rates (Glendinning & Enoka, 1994). Standardization of EMG onset designation procedures would minimize discrepancies due to such variations in the signal.

Motor time. Motor times reflect peripheral neuromuscular and physiological processes required to initiate and develop muscle activity. The significantly longer pretest motor time (148 ms) for persons with PD compared to the control group (119 ms) found in the current study was inconsistent with previous studies. Motor times have been found to be constant across experimental conditions with no differences between persons with and without PD (Pullman, et al., 1988; Sheridan et al., 1987; Stelmach et al., 1992).

In the present study, the lack of significant differences in motor times between the PD and control groups, was consistent with previous studies. The overall mean motor times were 126 ms for persons with PD and 108 ms for persons without PD in the current study. These values are comparable to the overall mean motor times of 103 ms and 119 ms for the PD and control groups found by Sheridan et al. (1987).

In contrast, Montgomery (1995) reported that motor times are often more abnormal for persons with PD than premotor times. He noted that in circumstances when movement begins against a background of antagonist activity, prolonged motor times in persons with PD may be due to abnormal agonist motor unit recruitment and synchronization, as well as abnormal antagonist derecruitment (Montgomery et al., 1991). In the present study, participants initiated their arm movement against a background of resting or silent agonist electromyographic activity as monitored on the oscilloscope. The antagonist triceps muscle was not monitored for resting levels. Antagonist muscle activity cannot be ruled out as influential on motor times in persons with PD in the current study.

Glendinning and Enoka (1994) also reported that motor unit activity differs in persons with PD compared to healthy, aging individuals and may contribute to akinesia and bradykinesia. Though Glendinning and Enoka (1994) did not specifically address motor times, they characterized motor unit behavior in persons with PD as having inconsistent discharge rates, increased number of motor units activated at low forces of contraction, and increased muscle coactivation. Such changes could account for longer motor times in persons with PD as observed in the present study.

Secondary disuse and weakness may also alter motor unit activity in persons with PD resulting from a slowing of movements, rigidity, and less active lives (Glendinning & Enoka, 1994; McGoon, 1993). Differences in fitness and lifestyle activity levels between the PD and control groups in this study may have contributed further to the differences in initial motor times (Spirduso; 1995).

Movement Time

Slowed MT is one of the most pervasive and debilitating characteristics of PD (Delwaide & Gonce, 1993; Isenberg & Conrad, 1994; Montgomery, 1995; Zappia et al., 1994). Slowing of movement is also characteristic of normal aging (Haaland, Harrington, & Grice, 1993), though controversy exists concerning the extent and nature of age-related differences (Pratt, Chasteen, & Abrams, 1994). As only a trend towards significant group differences for the MTs of the complex task was found for the current study, additional MT analysis was warranted. The coefficient of variation (CV) for MT was subsequently analyzed to examine the possible effects of performance variability on mean MT data. For the pretest, the MT CV was significantly greater for the PD group than the control group. A greater degree of response variability for the PD group may have influenced their mean MT score resulting in a lack of MT differences between the groups.

Summary

Persons with PD demonstrated similar RTs, premotor times, and MTs for the performance of rapid arm-reaching movements. Though this finding was unexpected, it demonstrates the specificity with which PD affects movement complexity, response programming, and execution. Persons with and without PD responded to manipulations of movement complexity in the same manner as healthy elderly individuals with increased processing time for more complex or difficult movements. Differences in motor times may be secondary to the disease or disuse effects. Similar MTs for the complex task for both groups may have been a factor of greater MT variability for persons with PD.

Effects of PD on Practice Effects for Response Programming and Movement Time

Practice is viewed as the most influential variable affecting response speed and skill acquisition (Ericsson & Charness, 1994, Lee, Swanson, & Hall, 1991; Schmidt, 1988; Spirduso, 1995). For the healthy older population, extended practice can decrease information processing time and subsequently improve the speed of movement responses to environmental stimuli and the speed of skilled performance (Murrell, 1970; Spirduso, 1995). A slowing of the physical speed with which older adults react and move is characteristic of the normal, aging process (Spirduso, 1995). This decline in speed impacts on every aspect of the aging individual's life including activities of daily living, employment, and recreational and social pursuits. Individuals with PD are particularly slower initiating and executing movements compared to healthy age-matched individuals (Montgomery, 1995). Consequently, the impact of slowed behavior on daily activities is compounded for persons with PD. Researchers to date have reported deficits in initial levels of motor performance for persons with PD and with practice, limited improvement in motor performance for persons with PD compared to the control groups (Frith et al., 1986; Harrington et al., 1990; Soliveri et al., 1992; Worringham & Stelmach, 1990). The benefits of practice on response and movement speed for persons with PD is critical to an understanding of the disease, motor behavior, and effective interventions for PD.

One of the major purposes of the current study was to explore and compare the benefits of practice on fast movement responses for persons with PD compared to the healthy, aging population. The effects of practice on the response programming of rapid arm-reaching tasks for persons with PD compared to age- and gender-matched controls will be discussed in the following section. Practice effects for response programming will be addressed relative to the dependent variables of reaction time and fractionated RT. To date, the effect of practice on fractionated RT has not been examined with the PD population. The effect of practice on the speed of execution or movement times will also be addressed.

Reaction Time

Practice decreases the movement complexity effect in healthy-young adults (Fischman & Lim, 1991; Fischman & Yao, in press; Hulstijn & Van Galen, 1983, Norrie, 1967a, 1967b; van Mier & Hulstijun, 1993) and between healthy-young and old adults (Light et al., in press). With practice or extended practice, mean RTs for the performance of complex tasks decreased to similar mean RT values for simple tasks. The time required for response programming or cognitive preparation of a movement response, in particular for complex tasks, is sensitive to practice.

In the present study, both participants with and without PD benefited from practice for response programming of the complex arm-reaching task. The significantly decreased RTs at the immediate retention test for both groups demonstrated the relatively immediate benefits of practice. More importantly, the effect of practice on RTs for both groups was sustained across a 48 hour rest interval. Sustaining the performance level across a retention period indicated a learning effect as compared to a temporary effect of practice.

Practice Effects and PD

The current study's finding that persons with PD benefited similarly from practice for response programming when compared to persons without PD is striking and a very significant finding. The previous literature has characterized the benefits of motor skill practice for persons with PD as limited with a slower rate of improvement and significantly less improvement compared to the outcomes for persons without PD (Frith et al., 1986; Harrington et al., 1990; Soliveri et al., 1992; Worringham & Stelmach, 1990). In the present study, the effect of a 2 day period of practice (120 trials each task) for response programming rapid, arm-reaching tasks was examined. Motor tasks in the practice literature for persons with PD have varied including target tracking with a semi-predictable target, target tracking with a novel control system, pursuit rotor time-on-target, timed sweater buttoning, and discrete aiming (Frith et al., 1986; Harrington et al., 1990; Soliveri et al., 1992; Worringham & Stelmach, 1990). Target tracking or pursuit tasks can be classified as closed-loop tasks requiring continuous feedback and on-line monitoring for successful performance. In comparison, the timed buttoning and discrete aiming tasks can be described as open-loop tasks which are preprogrammed when performed rapidly without the availability of feedback (Schmdit, 1988). The rapid, arm-reaching task in the current study is also an open-loop task and compares best to the timed buttoning and discrete aiming tasks. This distinction between closed- and open-loop tasks may be critical in distinguishing the deficits in motor behavior for persons with PD and the effects of practice as an intervention. A comparison of these studies to the current study is discussed next.

Overall, Frith et al. (1986) determined that persons with PD increased the time-on-target with practice of target tracking using a semi-predictable and novel control system. However, the control group improved better and faster than the PD group, especially for target tracking with a novel control system. Frith et al. (1986) categorized their target-tracking tasks within the scope of open-loop tasks. As a rationale for this categorization, these researchers noted that to perform this variation of a continuous tracking task, the learner must make temporary stimulus-response attachments or associations much like those required in a choice-RT condition for a discrete task. From their perspective, practice of these attachments led to program and skill development for continuous target-tracking.

Improvements in arm-reaching programming for persons with PD comparable to persons without PD in the current study and limited improvement in time-on-target (Frith et al., 1986) for persons with PD, regardless of the task, may have been due to differences in the number of environmental stimuli and their associated responses. The time-on-target task required continual monitoring for changes in the stimulus and then selection of an appropriate motoric response, whereas the arm-reaching study had a one-to-one, stimulus response relationship. Thus, a slower rate of improvement in the target tracking study may have been associated with the number of response choices. Frith et al. (1986) also attributed the slower rate for skill acquisition by persons with PD to a difficulty in the use of previously developed programs or skills in a novel circumstance or to a novel stimulus and a greater reliance on feedback early in learning. The rate of skill acquisition was not examined in the current study with only performance outcomes being examined on Day 2 and Day 3 following completion of practice.

Harrington et al. (1992) also studied continuous tracking performance in persons with PD on a pursuit rotor task. Their purpose was to examine procedural memory and skill learning relative to basal ganglia function by comparing the pursuit rotor, motor task, to a visuoperceptual task, mirror reading. To summarize the tracking performance, persons with PD (Harrington et al., 1990) demonstrated similar initial performance levels; improved with practice across three days, however, less so compared to the control group; and responded to increases in task difficulty similar to the control group. This pattern of findings parallels that for the current study with one major exception. Persons with PD practicing the two, arm-reaching tasks improved to the same degree for the control group. Thus, the rates of improvement differed in the pursuit rotor task with the PD group never achieving the level of performance of the control group. In contrast, Harrington and Haaland (1992) found that the PD and control groups demonstrated similar initial performance levels for mirror reading, as well as similar benefits to practice. In the current study, similar performance improvements were achieved by Day 2 of practice for the complex, arm-reaching task though the intermediate rate of performance change was not analyzed.

Two other practice studies involving persons with PD are more closely aligned with the current response programming study for arm-reaching tasks (Worringham & Stelmach, 1990; Soliveri et al., 1992). First, Worringham & Stelmach (1990) examined the effects of practice on the preprogramming for a discrete aiming task under simple and choice-RT conditions. Stelmach and Worringham (1990) found that persons with PD significantly decreased RTs only for the simple condition while the control group significantly improved RTs for the 4- and 8-choice conditions. These researchers concluded that persons with PD can preprogram movements given adequate practice and familiarity with a task. The equivalent benefits of practice for persons with and without PD determined in the current study further support Stelmach and Worringham's conclusion.

Stelmach and Worringham (1990) also observed initial similar simple and choice-RT responses for the PD and control groups though improvements for simple RT occurred at a slower rate for the PD group. Rates of skill acquisition are not comparable for the current study to the discrete-aiming study, however, they would be of interest due to the similarity in tasks and amount of practice. Stelmach and Worringham (1990) accounted for the slowed rate of change by speculating that the PD group began with a single strategy of response planning to the onset signal whether the condition was simple or choice-RT, then progressed with practice to differentiating strategies for the simple and choice-RT condition. Furthermore, persons with PD did improve somewhat in the 2-choice RT condition. Stelmach and Worringham judged that improvements were based on the potential to partially preprogram 2-choice RT conditions. Such improvements may be indicative of response-response compatibility effects on response programming (Light & Spirduso, in press). The additional distinction in practice effects for simple and choice-RT conditions in persons with PD extends the support for the view that the neural path for response selection may be dopaminergic whereas the path for response programming may not (Pullman et al., 1988).

Second, Soliveri et al. (1992) approached the study of practice in persons with PD from a more functional, ecological perspective by using the familiar task of cardigan buttoning. Their intent was to test the capacity in persons with PD for improvement of motor performance and the extent to which learning demands attention. Soliveri et al. (1992) found, as expected, that persons with PD button slower than the control group. Both groups improved with practice, but the control group reached a plateau, perhaps experiencing a ceiling effect. The rate of improvement with practice of buttoning alone was similar between the groups. With the introduction of a secondary simultaneous task, foot-tapping, both groups experienced detriments to performance though it had a greater effect on slowing the buttoning speed of the PD group. Continued practice by the control group of buttoning and foot-tapping eliminated the effect of interference from the tapping task on buttoning speed. However, dual-task practice by the PD group did not have equivalent performance benefits. Soliveri et al. (1992) concluded that persons with PD improved in performance with practice, however at a slower rate than controls. They posed that the rate-limiting factor for improvement may be the primary motor system dysfunction in PD as opposed to a motor learning deficit. For this reason, they suggested that persons with PD, even with extended practice, would never achieve the performance of persons without PD on speeded skilled tasks.

In contrast to Soliveri et al.'s findings (1992), in the current study equivalent RTs were determined both initially and following practice for initiation of rapid, arm-reaching tasks of varying complexity for persons with and without PD . From a theoretical perspective, persons with PD in the current, arm-reaching study demonstrated effective response programming and equal benefits of practice on motor learning. As commented by Soliveri et al.(1992), laboratory tasks often do not represent the complexity of daily, functional activities. The remarks of Soliveri et al.(1992) are critical when the implications for laboratory findings are extended to the real world for persons with PD. Certainly differences exist between the buttoning task and the arm-reaching tasks relative to movement complexity. The buttoning task requires repetitive, bimanual coordination of the upper extremities, particularly the fingers and thumbs for fine motor manipulation, and can be performed with relative ease without visual feedback. The arm-reaching task was a novel task for the participants requiring sequencing of arm reaches based on directional change and aiming for targets. The fine-motor manipulation and coordination was absent in the arm-reaching task and may be the defining factor for differences in improvement capacity for persons with PD.

Fractionated reaction time: Premotor time. In this study, the parallel decrease in premotor and RTs for both the PD and control groups due to practice was consistent with the practice literature for healthy individuals (Clarkson & Kroll, 1978; Lofthus & Hanson, 1981). However, the similar effect for persons with PD has not been previously reported in the literature. The effect of practice on motor learning and response programming relative to fractionated RTs in persons with PD is a new contribution to the literature. With practice, persons with PD improved the cognitive processing component of reaction time in preparing the more complex movement and demonstrated relatively lasting effects on premotor time. Such sustained improvements have significant implications concerning the use of practice for re-training motor behavior in Parkinsonian patients.

Fractionated reaction time: Motor time. Motor times typically remain constant across practice sessions for healthy individuals though exceptions have been noted (Lofthus & Hanson, 1981). In this study, overall mean motor times decreased from the pretest to immediate retention test only for persons with PD, while motor time remained consistent for the control group. The improvement in motor times for the PD group persisted without further significant change at the delayed retention test. Variability in motor times may account for the distinct findings for persons with PD, yet the mean CV for motor times was significantly greater for persons with PD than the control group across all conditions.

A change in neuromuscular coordination or adaptation may also account for the change in motor times in persons with PD from the pretest to the immediate retention test. Glendinning and Enoka (1994) proposed that, due to changes in motor unit behavior with PD, strength training may improve performance and function in persons with PD. Though participants in the current study did not participate in strengthening exercises, with practice participants with PD may have benefited from increased familiarity with the task and heightened neuromuscular activity. Possible decreases in motor times for persons with PD occurred with improved consistency of motor unit discharge rates or decreases in muscle coactivation

Effects of PD on Practice for Movement Time.

Across age groups for healthy individuals, practice is a critical variable for improving the speed of a response (Carnahan, Vandervoort, & Swanson, 1993; Lee, Swanson, & Hall, 1991; Light et al., in press; Salthouse & Somberg, 1982). Fast responses are dependent upon both RT and MT components (Spirduso, 1995). Behaviorally, MT is the speed with which individual can move their limbs and is related to the peripheral contractile processes of the muscle. Slowness in the execution of movements has a significant impact on the performance of everyday activities whether such slowness is due to healthy aging or disease processes such as Parkinson's. Intervention to maintain speed of performance is thus advantageous and important for both populations.

With practice, persons with PD improved the speed of buttoning under both single and dual-task interference conditions (Soliveri et al., 1992), though group differences persisted. For the present study, the decrease in movement times for both PD and control groups practicing the complex movement was consistent with the literature (Light et al., in press). The fact that improved MT was maintained for both subject groups upon delayed retention is one of the most important findings in this study. Practice may be particularly beneficial for increasing the performance speed of persons with PD. For the PD group, practice also improved within-participant MT consistency as seen by the significant decrease in CV from pretest to immediate retention and the maintained improvement through the delayed retention test (See Appendix J). In addition to improved movement execution speed, improved consistency of performance is an extremely important benefit of practice.

Furthermore, Soliveri et al. (1992) demonstrated that with practice the interference effects of a secondary task on buttoning speed diminished. This paradigm was used to test the degree of automaticity achieved with practice. Although the dual task paradigm was not used in this study, sustained performance at the delayed retention test is a powerful test and indicator of motor learning effects.

Feedback and Goal-setting as a Practice Variable

The use of summary feedback throughout the practice sessions may have served as an additional motivating factor for task persistence and performance improvement by the participants (Salmoni, Schmidt, & Walter, 1984). The use of feedback has not been reported previously in the literature relative to persons with PD. In the current study, participants received summary feedback for total response time for every other trial and immediately following completion of a set of 10 trials. Participants were encouraged to use this information to monitor their progression and to set goals for improvement of speed of performance. On Day 2, the experimenter also compared the participant's response time scores for the first set of trials on Day 2 with the final response times for the last set of trials on Day 1.

Summary

Persons with PD benefited similarly to practice of the two, fast arm-reaching tasks for RT, premotor time, and MTs when compared to persons without PD. In particular, response programming and movement execution speed of the more complex task improved with practice. The movement complexity effect was sensitive to practice for both PD and control groups with the effect diminished by practice. These findings are significant and important. Though performance improvements have not been consistent across practice studies in the PD population, this study demonstrated the benefit of practice and the capacity to learn in the performance of fast, predictable arm-reaching responses. Persons with PD were able to use a predictable, environmental stimulus as a cue for programmed responses of rapid aiming with arm-reaching. In addition, a learning effect for these improvements was sustained across a 10 minute and 48 hour rest interval. Determining this learning effect for persons with PD is important in justifying practice as an effective rehabilitation intervention to improve motor performance in persons with PD.

Transfer

In motor learning, the issue of transfer concerns how learning one task affects the performance or learning of another task. Motor skill transfer is valuable when teaching similar skills or developing rehabilitation strategies to maximize learning time and intervention (Schmidt & Young, 1987; Winstein, 1991). Transfer capabilities have been demonstrated for older adults. Older adults, practicing novel video games, not only improved their video scores but also demonstrated generalization of the skill to performance of a 2-choice RT task (Clark, Lanphear, & Riddick, 1987; Dustman, Emmerson, Steinhaus, Shearer, & Dustman, 1992).

The Box and Block Test, a timed test of manual dexterity, was used in the present study as the transfer test for the practice of the rapid, complex arm-reaching task. The overall mean BBT scores for the control group (66 blocks) was consistent with the normative data for 360, healthy participants, mean age of 72 (68 blocks) (Desrosiers et al., 1994) . The PD overall mean BBT score of 56 blocks was significantly less than the control group, although it was higher than the average score for a group of 34 subjects with varying upper limb, neurological impairments (Desrosiers et al., 1994); (42 blocks) . To date, researchers have not specifically examined the relationship between Box and Block Test scores for persons with and without PD.

Scores on the BBT increased by 2 blocks from Day 1 to Day 2 for both groups with this increase approaching significance. A direct conclusion for transfer of arm-reaching practice to Day 2 - Box and Block Test scores cannot be made without additional PD and control groups which did not practice the arm-reaching tasks. However, Desrosiers et al. (1994) noted that the Box and Block test-retest reliability for healthy individuals (M = 72 years) performed across an average interval of eight days was an intraclass correlation coefficient (ICC) of .90. For individuals with disabilities affecting the upper extremity (M = 75 years), the test-retest reliability across the eight day period was ICC .97. The test-retest for the BBT in the current study using Pearson's correlation coefficient was .86 for the control group and .98 for the PD group. The test-retest scores were thus significantly correlated for both groups and both groups demonstrated an improvement in Box and Block Test scores from Day 1 to Day 2.

In a study of 15 older adults with cerebral vascular accidents and matched-controls, Box and Block Test scores significantly improved by 1 block from pretest to posttest within a 1 week interval, regardless of whether or not the groups participated in brief, upper extremity exercise (Pearson, Smyth, Pendergrass, Longway, & Freund; manuscript in preparation). In the current study, participants with and without PD improved by 2 blocks across a 2 day interval, though both groups had practiced the arm-reaching tasks for 120 trials each prior to the BBT on Day 2. The improvement differences between the current study and the Pearson et al. study may indicate transfer effects for the current study and warrants further investigation.

The Pearson product moment correlation was performed as a test of association between the BBT scores and the complex task for Day 1 and then Day 2. The variables of RT and MT were correlated separately with the Box and Block Test. Of particular interest when comparing the Box and Block Test scores and the arm-reaching task is a lack of association for performance of the two tasks, particularly by persons with PD. If practicing the arm-reaching task provided and element of transfer to the Box and Block Test, then RT or MT would be expected to be negatively correlated with Box and Block Test scores. No association was found between the complex arm-reaching task RTs and MTs and the BBT scores for the PD group. Significant, negative associations were found for the control group with BBT scores relative to RT on Day 1 and with MT relative to Day 2. Though the associations for the control group were inconsistent across Day 1 and Day 2, the correlations did indicate a potential performance association between the two tasks for the control group.

Box and Block Test scores were significantly different between the groups with and without PD. As discussed previously, finding the BBT scores to be different but no group differences in the RTs for the arm-reaching tasks is important to the understanding of the motor problems in PD. The BBT score, a timed, validated task for manual dexterity, more closely represents the problem of bradykinesia associated with PD. The predominant component of the BBT is movement execution as compared to movement preparation or initiation. Bradykinesia is defined as a slowing of movement execution. Timed functional tasks, similar to the BBT, may be pertinent in the evaluation of motor dysfunction in PD, as well as in reassessment following intervention (Soliveri et al., 1992; Podsiadlo & Richardson, 1991). An important, desirable outcome of rehabilitation intervention for persons with PD is the successful performance of daily activities in a safe and efficient manner. The significant difference in Box and Block Test scores for persons with and without PD, as determined in this study, points to the potential application of timed functional movements in both rehabilitation and research efforts with persons with PD.

Transfer Summary

A definitive conclusion cannot be made concerning the transfer of practice and learning of the arm-reaching tasks to the performance of the BBT of manual dexterity. Though both PD and control groups improved BBT scores from Day 1 to Day 2, the improvement only approached significance. Comparison to PD and control groups who did not practice the arm-reaching tasks would be necessary to differentiate a transfer effect from a test-restest effect. Correlational analyses did not further support an association between arm-reaching task speed of performance and BBT scores, in particular for persons with PD. Significant differences in BBT scores between the PD and control groups provided definite evidence for a deficit in motor performance in persons with PD.

Summary

The purposes of this study were to: (1) determine the performance differences between persons with and wihout PD for each component of rapid movement responses of varying complexity, (2) examine the differential effects of practice on altering each of the movement response components in tasks of varying complexity for persons with and without PD, and (3) determine transfer of the practiced rapid movement responses on performance of an upper limb motor skill. Specifically, the effects of PD, movement complexity, and practice were studied.

Persons with PD and age- and gender-matched controls practiced two, rapid arm-reaching tasks of different movement complexity. Movement complexity varied between the two tasks by the number of steps in the movement sequence and the number of directional changes in the movement. Participants practiced each task for 120 trials across a 2 day period. Response programming was studied by analyzing the overall RT latency of each movement and the fractionated subcomponents for RT: premotor and motor time. Premotor time represents the contribution of central nervous system processing to RT, whereas motor time is the peripheral component. A learning effect for practice was examined by comparing the responses for a pretest to those for an immediate (10 minute rest interval) and delayed retention test (48 hour rest interval).

The complexity by test session results of this study demonstrated that, initially and following practice, persons with and without PD demonstrated similar response programming and movement execution speeds as manipulated by movement complexity. For both groups, RTs and premotor times were significantly longer for the more complex task indicating a movement complexity effect. With practice of the two, arm-reaching tasks, both persons with and without PD exhibited improved response programming and movement execution speed for the complex task and a learning effect for each of the retention intervals.

Finding that with practice, persons with PD significantly improved response programming and movement execution speed for a complex movement sequence is the most significant and important finding of this study. From a theoretical perspective, the effects of PD have not limited the capacity of individuals in the current study to improve motor performance, response speed, based on practice. Practice had a beneficial effect on the performance of fast, discrete, complex arm-reaching responses to a predictable environmental stimulus. The particular benefit of practice for the components of a fast, complex movement response were on: (1) premotor time, the cognitive component of information processing, (2) motor time, the peripheral component of RT, and (3) movement execution speed. Practice benefited both speed and consistency of response performance. Based upon the retention test findings, motor learning for this type of task appeared equally beneficial for persons with and without PD. Differences in the rates of skill acquisition and the amount of practice required by persons with PD compared to persons without PD to alter response speed significantly was not addressed within the scope of this study. Similarly, though execution speeds improved for both PD and control groups, changes of the time intervals within response execution were not examined. Future analysis of this comparison for rate of skill acquisition and the effect of practice on the intratarget response time intervals comprising task execution may add to an understanding of the relative benefits of practice in PD.

From a clinical and intervention perspective, practice is viewed as an effective variable for improving response speed in persons with PD. The benefits of practice are specific though to the performance of rapid, discrete, sequential responses of arm-reaching movements. In the literature to date, the extent of the benefits of practice on speed of performance in persons with PD has been shown to be limited and perhaps task specific. In this study, practice had beneficial effects on both cognitive and peripheral components of fast movement responses. Everyday lives are filled with tasks requiring the performance of rapid, discrete, aiming movements. The benefits of practice to other ballistic, functional movements is implied from the findings of this study. Perhaps typing speed can be improved in persons with PD, but could rolling over in bed be more easily accomplished if practiced and performed as a more ballistic task using momentum? Answers as to the functional benefits of practice on performance speed for persons with PD are not known. However, the implications from this study encourage the testing of such potential in persons with PD.

Transfer of the arm-reaching skill to a manual dexterity skill, the Box and Block Test, was also explored in this study. Persons with PD demonstrated a deficit for timed manual dexterity compared to persons without PD, as well as a lack of association between performance on the BBT relative to RT and MTs for the complex, arm-reaching task. In contrast, comparison of the movement times for executing the complex arm-reaching task between persons with and without PD only approached significance, with equivalent MTs found for the simple task. Significantly different BBT scores between the two groups though clearly reflected group differences for movement execution speed. The BBT may be a more sensitive instrument for the assessment of motor deficits in persons with PD than the arm-reaching task. The additional task components for fine motor coordination and manipulation in the BBT may affect the speed of performance. Following practice of the arm-reaching tasks, persons with and without PD improved their manual dexterity by 2 blocks indicating a possible transfer or test-retest effect. The extension of timed tasks to more functional tasks and contexts may prove beneficial for the analysis of motor deficits in persons with PD. More importantly, the use of timed functional movements may be a meaningful instrument to measure the efficacy of interventions for improving the speed of functional tasks pertinent to persons with PD.

Conclusions

From the findings of this study, the following conclusions are made.

(1) The movement initiation problem, reported in PD literature, is not attributed to the effects of movement complexity, as manipulated by number of sequence parts and number of directional changes, on response programming of rapid, arm-reaching tasks.

(2) The movement complexity effect on response programming is supported for persons with and without PD and indicates that greater central nervous system time is required to prepare more complex movements than simple movements.

(3) Practice of the arm-reaching tasks is beneficial in reducing the movement complexity effect on response programming in persons with and without PD.

(4) For persons with and without PD, practice has an equivalent learning effect across a 10 minute retention interval and 48 hour retention interval for improving response programming and reducing movement execution speed of a complex, arm-reaching task.

(5) Persons with PD demonstrate slowed movement execution speed compared to persons without PD for both a rapid, complex arm-reaching task and for timed manual dexterity demonstrated in the Box and Block Test.

(6) Following practice of the arm-reaching tasks by participants with and without PD, similar improvements in manual dexterity by persons with and without PD for the Box and Block test indicate either a transfer or test-retest effect.

Implications for Future Research

Based on the findings of this study, several lines of inquiry are suggested for future study concerning movement initiation and execution, movement complexity, and practice in persons with PD.

(1) In the current study, the finding that response programming was not impaired in persons with PD performing rapid, arm-reaching tasks does not preclude impairment from being observed under different movement and task conditions. PD does not affect similarly all movements in all environments (Montgomery, 1995). As emphasized by Jones et al. (1994), not all motor tasks may demonstrate the complexity required to note deficits in response programming in persons with PD. The extent of the response programming deficit may be dictated by critical movement characteristics. Researchers have suggested that a hierarchy of motor disorders may exist in PD dependent on the complexity of the movement to be performed (Viallet, Massion, Massarino, & Khalil, 1987). The use of a battery of varied motor tests may be of greater benefit in understanding the specific effects of PD on motor behavior and function.

(2) Performance of the two arm-reaching tasks of varying complexity did not result in group differences in RT, thus raising the question of what types of movement complexity are problematic for persons with PD. The Box and Block Test scores certainly indicated differences between those with and those without PD for the performance of a timed, repetitive task requiring grasp, transport, and release of 2.54 cm cubes from one side of a box, across a partition, to the opposite side. The Box and Block Test and the arm-reaching tasks both required rapid, alternative movements of the shoulder and elbow. However, the Box and Block Test further required fine-motor coordination and successive grading of force for grasp and release. These characteristics may distinguish the two tasks and be two of the critical requirements for understanding the movement initiation and execution problems associated with PD. Movement complexity may be manipulated in many ways (Christina, 1992; Spirduso, 1995) and each type and amount of complexity may

have different effects on motor behavior for persons with PD. The skill of handwriting may be an interesting functional task to investigate from both a theoretical perspective concerning movement complexity and for practical benefits for persons with PD. Perhaps difficulties in handwriting experienced by persons with PD are associated with the fine-motor coordination deficits seen for BBT performance.

(3) From an ecological perspective, a timed motor task is exemplary of the everyday problem for persons with PD. Persons with PD accomplish daily functional tasks in a slower time period relative to their healthy peers. Studying the timed performance of typical tasks of everyday living may narrow the scope of tasks to which persons with PD have difficulty. Comparative analysis of timed functional movements in persons with and without PD may lead to identification of the dimensions of complexity contributing to slowed RT and/or MT (Soliveri et al., 1992; Podsiadlo & Richardson, 1991). The functional context itself may be relevant to complexity effects for persons with PD. Continued systematic investigation of the dimensions of movement complexity relative to functional, motor deficits in persons with PD may contribute to our understanding of the PD movement dysfunction and direct our treatment intervention.

(4) Another aspect of movement complexity is multi-limb coordination that involves the preparation of the movement response, as well as the coordination of the actual movement execution. In this study, only movement execution speed was examined. As suggested by previous researchers, persons with PD may have difficulty in the organization and integration of movement (Harrington and Haaland,1990; Stelmach et al., 1987; Warabi, Yanagisawa, & Shindo, 1988). Differences in the timing of intraresponse intervals have been reported indicating a breakdown or simplification of movement sequences. Similar analyses may be conducted on the current data to examine the actual movement execution patterns identified by time intervals between switches. For example, from casual observation during data retrieval and identification for the current study, the researcher noted that persons with faster response times tend to develop equidistant times between

switches. Such a response pattern may be a strategy participants used to simplify the task for optimal performance.

(5) Practice benefits for persons with PD need to be evaluated for their specificity and persistence over time. The current study demonstrated practice benefits for a specific laboratory task relative to response progamming. These finding may be relevant to practice of discrete, goal-directed movements required for driving or typing. However, the benefits of such practice to functional tasks are unknown to date. The literature shows limited benefits under other laboratory circumstances. Furthermore, the amount of practice may certainly vary relative to the task. Would walking practice under various instructional cues have a long-term beneficial effect on the walking patterns in persons with PD? How long would the benefits be sustained? The effect of practice or the effect of any intervention on increasing the speed of performance for everyday tasks is more relevant and important to persons with PD (McGoon, 1993).

(7) The rate of skill acquisition was not addressed in the present study. Researchers have previously reported slower rates of skill improvement with practice for persons with PD. The acquisition trials for this study could be analyzed in the future to assess and compare the rates of skill acquisition between persons with and without PD. The amount of practice required for both groups to improve to the performance levels observed on the Day 2 retention test would be important in better understanding the extent of practice benefits.

(8) The transfer findings on the BBT in the current study were inconclusive predominantly due to the lack of control groups who did not practice the arm-reaching tasks. Further investigation of potential transfer effects is warranted based on the preliminary findings and comparable test-retest findings of other studies.

(9) Efforts were made to ascertain a homogeneous PD group by limiting participation to individuals at stages I and II of the Hoehn and Yahr disability scale. The nature and consequences of PD may have contributed to heterogeneity within the

population with subsequent impact on variation of task performance. Follow-up assessment of task performance on an individual basis may be beneficial in ascertaining patterns of differences within the PD group. Such assessment may lead to classification of individuals with PD based on the type or pattern of task performance and thus necessitate varying intervention strategies.

Table 8. Comparison of Studies on Reaction Time in Parkinson's Disease

	Method and Findings				
	Participants	Experimental Task	Reaction Time Mean (ms)		Medication State
Reference			Parkinson's	Control	
Evarts et al., 1980	M = 61 years	Simple RT, supination	399	309	On medication
Light et al., in press	M = 70 years	Simple RT, 1 step arm reach Simple RT, 3 step arm reach	--- ---	331 350	Not applicable
Pullman et al., 1988	M = 49 years	Simple RT, rapid wrist flexion	350	250	On medication
Rogers & Chan, 1988	M = 60 years	Simple RT, ballistic plantarflexion	344	353	On medication
Current study	M = 74 years	Simple RT, 1 step arm reach Simple RT, 4 step arm reach	314 354	297 337	On medication

APPENDIX A

PARTICIPANT QUESTIONNAIRE INCLUDING KATZ ACTIVITIES OF DAILY LIVING AND GERIATRIC DEPRESSION SCALE

For our records, please fill out the following information prior to your first appointment. It should take you approximately fifteen minutes to complete this questionnaire. Bring the completed questionnaire with you to your first appointment. Thank-you.

SUBJECT RECORD DATE:____________

Name: ____________________________Gender: Male / Female (Circle one).

Date of Birth: __________________

Address: _________________________City:__________________

State:____________ Zip code:__________

Educational level: (select one) __________

0-16 = through college, 18 = master's level training 20 = doctoral level training (Ph.D., M.D.)

Occupation: _________________________

Date of onset/diagnosis of PD:___________(year)__

Do you participate in any regular physical or therapeutic activity?

If so, what ______________________how often? _______how long?_____

____

******You must be right-handed to participate in this study.******

Are you right-handed? YES - NO (Circle one).

If **YES**, please continue filling out this questionnaire.

If NO, please contact Andrea Behrman at (904) 373-7088.

Do you have any medical history of:

Other neurologic disease	**YES**	**NO**
Mental disorder	**YES**	**NO**
Severe cardiovascular disorder	**YES**	**NO**
Right arm injury, pain, or weakness	**YES**	**NO**

If you responded **YES** to any of the above concerning your medical history, please explain.

____

____

____

What medications do you currently take? Please list your dosage and frequency?

Medication name	Dosage	Frequency
1.		
2.		
3.		
4.		

Please choose the best answer (YES or NO) to describe if you are independent in performing the following daily activities:

		INDEPENDENT	
1.	**Bathing** (sponge bath, tub bath, or shower)		
	Receive either no assistance or assistance in bathing only 1 part of body.	**YES**	**NO**
2.	**Dressing**		
	Gets clothes and dresses without any assistance except for tying shoes.	**YES**	**NO**
3.	**Toileting**		
	Goes to toilet room, uses toilet, arranges clothes, and returns without any assistance (may use cane or walker for support and may use bedpan or urinal at night.	**YES**	**NO**

4. **Transferring**

Moves in and out of bed and chair without assistance (may use cane or walker). **YES** **NO**

5. **Continence**

Controls bowel and bladder completely by self (without occasional "accidents"). **YES** **NO**

6. **Feeding**

Feeds self without assistance (except for help with cutting meat or buttering bread). **YES** **NO**

Choose the best answer for how you felt the past week.

1. Do you often get bored? **YES** **NO**
2. Do you often get restless and fidgety? **YES** **NO**
3. I feel in good spirits. **YES** **NO**
4. Do you feel you have more problems with memory than most? **YES** **NO**
5. I can concentrate easily when reading the papers. **YES** **NO**
6. Do you prefer to avoid social gatherings? **YES** **NO**
7. Do you often feel downhearted and blue? **YES** **NO**
8. Do you feel happy most of the time? **YES** **NO**
9. Do you often feel helpless? **YES** **NO**
10. I feel worthless and ashamed about myself. **YES** **NO**
11. I often wish I were dead. **YES** **NO**

APPENDIX B

MINI-MENTAL STATE EXAMINATION (FOLSTEIN ET AL., 1975)

Maximum Score	Score	
		ORIENTATION
5	______	What is the year, season, date, month?
5	______	Where are we: state, county, town, address, street #?
		REGISTRATION
3	______	Experimenter names three objects (1 second to say each), asks subject to repeat all three. One point is awarded for each correct answer. Repeat as necessary, until he/she learns all three. Trials are counted and recorded.
# Trials	______	
		ATTENTION AND CALCULATION
5	______	Spell "world" backwards.
		RECALL
3	______	Ask for the three objects repeated above.
		LANGUAGE
2	______	Name the object: a pencil and a watch.
1	______	Repeat the following: "No ifs, ands, or buts."
3	______	Follow a three-stage command: "Take a piece of paper in your right hand, fold it in half, and put it on the floor."
1	______	Read and obey the following: "CLOSE YOUR EYES."
1	______	Write a sentence.
1	______	Copy this design.
Total Score	___/ 30	

APPENDIX C

PARTICIPANT PHYSICAL AND NEUROLOGIC SCREEN

SUBJECT NAME: ____________ DATE: _______

1. Can the participant read letters (size of switch diameter) placed on the five target switches? **YES NO**
2. Can the participant readily identify the sound of the response onset stimulus, the buzzer? **YES NO**
3. Does the participant exhibit normal proprioception of the right shoulder? **YES NO**
4. Can the participant reach all five target switches comfortably? **YES NO**
5. Does the participant exhibit spasticity of the right biceps (quick stretch)? **YES NO**
6. Does the participant exhibit normal finger-to-nose responses with the right hand (cerebellar function)? **YES NO**

APPENDIX D

HOEHN AND YAHR DISABILITY SCALE (1967)

Stage I. Unilateral involvement only, usually with minimal or no functional involvement.

Stage II. Bilateral or midline involvement, without impairment of balance.

Stage III. First sign of impaired righting reflexes. This is evident by unsteadiness and as the person turns or is demonstrated when he is pushed from standing equilibrium with the feet together and eyes closed. Functionally, the person is somewhat restricted in his activities, but may have some work potential depending upon the type of employment. Persons are physically capable of leading independent lives, and their disability is mild to moderate.

Stage IV. Fully developed, severely disabling disease; the person is still able to walk, and stand unassisted but is markedly incapacitated.

Stage V. Confinement to bed or wheelchair unless aided.

APPENDIX E

LETTER OF APPROVAL FROM INSTITUTIONAL REVIEW BOARD FOR THE RIGHTS OF HUMAN SUBJECTS

UNIVERSITY OF
FLORIDA

Institutional Review Board

114 Psychology Bldg.
PO Box 112250
Gainesville, FL 32611-2250
Phone: (904) 392-0433
Fax: (904) 392-0433

August 17, 1994

TO: Ms. Andrea L. Behrman & Dr. James H. Cauraugh
25 FLG

FROM: C. Michael Levy, Chair,
University of Florida Institutional
Review Board

SUBJECT: Approval of Project # 94.337
Analysis of the movement initiation problem in Parkinson's disease:
Practice as an intervention

I am pleased to advise you that the University of Florida Institutional Review Board has recommended the approval of this project. The Board concluded that your subjects will not be placed at risk in this research. Given your protocol it is essential that you obtain written informed consent from each participant. This approval, however, is conditional upon your submitting to the IRB a copy of your approved informed consent form that includes the following phrase in the upper or lower margin: "Approved for use through August 17, 1995."

If you wish to make any changes in this protocol, you must disclose your plans before you implement them so that the Board can assess their impact on your project. In addition, you must report to the Board any unexpected complications arising from the project which affect your subjects.

If you have not completed this project by August 17, 1995, please telephone our office (392-0433) and we will tell you how to obtain a renewal.

By a copy of this memorandum, your Chair is reminded of the importance of being fully informed about the status of all projects involving human subjects in your department, and for reviewing these projects as often as necessary to insure that each project is being conducted in the manner approved by this memorandum.

CML/h2

cc: Vice President for Research
College Dean
R. Singer
Foundation for Physical Therapy Research

APPENDIX F

INFORMED CONSENT FORM

Informed Consent Form to Participate in Research
University of Florida
Gainesville, Florida 32610

You are being asked to participate in a research study. This form is designed to provide you with information about this study and to answer any of your questions.

1. Title of research: Analysis of the Movement Initiation Problem in Parkinson's Disease: Practice as an Intervention.

2. Principal investigator (s):
Andrea Behrman, M.S. P.T., Doctoral student,
Exercise & Sport Sciences, (904) 373-7088
James H. Cauraugh, Ph.D., Associate Professor,
Exercise & Sport Sciences (904) 392-0584/392-9575

3. Purpose of the research: Persons with Parkinson's disease have difficulty initiating movement. The purposes of this study are first, to analyze this difficulty by comparing fast arm-reaching movements performed by persons with and persons without Parkinson's disease and second, to determine the effects of practice on performing fast arm-reaching movements.

4. Procedures of this research: This study will be conducted on three, consecutive days. For persons with Parkinson's disease, your appointments for participation in this study will be scheduled at a time that you feel your medication is most effective (during an "on" period) and at your convenience. For persons without Parkinson's, you will also be scheduled at your convenience.

First day: You will be asked questions concerning your medical history and daily activities and evaluated by brief tests of cognitive abilities (for example, your memory or attentiveness) and depression. If you have Parkinson's disease, the severity of your disability will be classified according to your physical abilities and responses to questions concerning your abilities. You do not have to answer any question you do not wish to answer.

You will be seated comfortably with your arms supported at a table in front of you. The testing apparatus on the table consists of telegraph keys. Two movement patterns among the keys will be demonstrated to you. In order to record your muscle activity during movement responses, an electrode (about the size of a dime) will be placed on your skin over your right biceps muscle and a similar electrode placed on the skin over your right deltoids muscle and held in place with a wrap. You will be asked to practice several times, with your right hand, each movement (a simple reach sideways and a three-part reach changing directions twice). Each trial will be started by a warning sound, then a green light to tell you to begin performing the movement as quickly as possible. On the first day, you will tested by performing 20 trials of each of the two movements, as indicated and 40 trials in which you will not know which movement to perform until a light comes on indicating which movement to perform. Then, you will perform 200 practice trials, as described for the 40 test trials, but with verbal feedback provided for each trial concerning the speed of your response. You will be given time to rest between trials, after every 10 trials, and every 50 trials. The electrodes will be removed at the end of the practice session. This session will last no more than two hours.

On the second day, you will practice both movements for 400 trials, again with the movements not specified until the light indicates the correct movement response, and with feedback for every trial. You will be given rest periods as described for the first day. This session will last approximately one and a half hours.

On the third day, the electrodes will be replaced on your arm muscles and you will be tested in the identical manner as the first day; thus 20 trials of each movement, then 40 trials of the movements not pre-specified. This session will last no more than 30 minutes.

Throughout this study, your particular results will only be identified by a subject coded number to ensure your identity remains confidential. In any future publication of the findings of this study, typically only group average performance scores are reported.

You will be compensated $50.00 for your participation in this study by completing the three consecutive days of testing and practice.

5. Potential risks, or discomforts: Participants may experience slight mental fatigue from concentrating on performing the movements; minimal, muscle fatigue from repeating the movements; and stiffness from sitting. We will try to minimize your fatigue by seating you in a comfortable chair with the height adjusted to fit you. Rest periods will be provided consistently during the testing. At any time that you wish to additionally rest, stand, or stretch, testing will be discontinued to allow you to do so until you state that you are ready to continue.

6. Potential benefits: All subjects may benefit from the social interaction associated with participation in this study. Participants monitoring performance feedback will find out how fast they reach with their arm in response to a visual stimulus (a light), how fast they perform a sequence of arm-reaching movements, and any changes in performance with practice of the movements.

7. Alternative treatment or procedures: Participation in this study does not preclude you from continuing any ongoing rehabilitation or therapy for Parkinson's disease. Choosing not to participate in this study will in no way affect your care. You are free to withdraw your consent and to discontinue participation in the project or activity at any time without prejudice.

8. Questions. Should you have any questions concerning this study, its procedures, risks, or benefits, please contact one of the following individuals to answer your questions:

Andrea L. Behrman, Motor Behavior Lab, 25 Florida Gym, University of Florida
(904) 373-7088, (904) 392-9575
James H. Cauraugh, Motor Behavior Lab, 25 Florida Gym, University of Florida
(904) 392-9575, (904) 392-0584

I have read and I understand the procedure described above. I agree to participate in the procedure and I have received a copy of this description.

____________________ ____________________
(Participant's signature) (Date)

____________________ ____________________
(Principal investigator's signature) (Date)

Approved for use through August 17, 1995.

APPENDIX G

POWER ANALYSIS, METHODOLOGICAL CONSIDERATIONS, AND PRELIMINARY STUDIES

Sample Size

A review of the literature is provided to determine the typical number of subjects with PD included in motor behavior research. The range of number of subjects with PD tested in 13 motor behavior studies published from 1981 through 1993 is 6 to 29 with a mode of 12. The number of subjects with PD tested in practice or training studies in five studies published from 1986 to 1993 were 7, 10, 12, 20, and 21. In addition to the usual difficulties in acquiring subjects, reasons which may account for the limited number of subjects with PD participating in such studies range from the nature of the subject population (patients with neurologic disease), the age of the population, diminishing mobility in the population, fluctuations in daily levels of activity, variability in the population, and general access to or availability of the population.

The sample size is based on a power test (Marks, 1982) with data for performance of both simple and complex movements (Light et al., in press) by healthy, older adults (M age = 68 years) for 160 trials of practice. A sample size of 14 subjects was calculated from the following factors: a 60 ms critically significant difference in RT for the complex movement pre- to post-test (Preliminary Study 6 - MW), standard deviation of 88.0 ms (Light et al., in press), alpha level of .05, and .80 power minimum. These values are based on previous research and preliminary studies. Value changes for the standard deviation and size of the significant difference in the dependent variables from those projected, while maintaining an alpha of. 05 and a power of .80, may certainly alter the required number of subjects.

Further power tests were performed with data from Stelmach et al.'s work (1987), indicating a 68 ms standard deviation for a 329 ms average RT for 6 Parkinsonian subjects performing a 5-tap finger sequence. In this instance with a 50 ms difference again defined as critical, 11 subjects per group would be required. With a 100 ms difference proposed as critical, 6 subjects per group would be required to achieve .80 power. Based on the power tests, as described, and review of the literature, 15 subjects with and 15 subjects without PD will be included in this study.

Methodological Considerations

Background information pertinent to selection of the methods is included in this section. Four areas are addressed including task selection, fractionating RT, retention test and transfer design, and compliance and attrition.

Task Selection

The task selected for this study was chosen based on a strict definition of movement complexity as described by previous researchers (Anson et al., 1994; Christina, 1992; Fischman, 1984; Henry & Rogers, 1960; Light et al., in press). Movement complexity will be varied according to the number of movement components in a sequence and to the number of directional changes. The first movement component of the complex task and the simple task are identical movements controlling for differences in peripheral requirements (Anson, 1982; 1989; Christina, Fischman, Vercruyssen, & Moore, 1982; Kerr, 1978). The size of the targets is uniform and large enough to maintain performance of an open-loop task not requiring excessive feedback for accuracy. The target switches are red, a distinctive, high contrast color. Participants will be required to complete each movement sequence by cessation of the movement on the last target for consistency of task performance and complexity demands (Rand, De Witt, & Stelmach, 1994).

The tasks have been previously tested in a practice study comparing younger and older adult performance. Healthy older adults with a mean age of 68 years, comparable in age of the Parkinson's population, were able to successfully perform the tasks in a similar experimental set-up (Light et al., in press). Persons with PD (mean age 58) have demonstrated the capacity to perform ballistic, complex arm movements (Beradelli, Accornero, Argenta, Meco, & Manfredi, 1986).

Fractionating Reaction Time

To understand the practice effect on the plasticity of the Parkinson's induced movement initiation problem, a method of response component analysis is useful. Separating the components of a speeded-movement response into the premotor and motor times of the RT while also exploring MT allows the problem to be localized. Premotor time is considered to represent the central processing time relative to response programming. Motor time reflects peripheral aspects of movement preparation such as tension development in the muscle. Movement time is indicative of the peripheral components relative to movement execution.

To date, this analytical strategy has not been applied to a comparison of the effects of practice on speeded-movement responses of varying complexity and their components in healthy, older adults and persons with PD. Such an analytical approach may provide a means to discern the relative contributions of each component of speeded-movement responses to the problem of movement initiation in persons with PD and to the efficacy of practice as an intervention for performance of simple and complex movements. Note that fractionation of RT in persons with PD has revealed a delay in premotor time, consistent with deficits in central processing (Evarts et al., 1981; Sheridan et al., 1987; Stelmach et al., 1992).

Retention Test and Transfer Design

A long-term retention (48 hours) test and a transfer test will be used to assess learning post-practice trials. Motor learning is a relatively permanent change in the capacity to respond, due to practice or experience (Hilgard & Bower, 1975; Salmoni, Schmidt, & Walters, 1984). The experimental design must provide for distinguishing between the temporary effect variables (i.e. fatigue) may have on performance versus the relatively permanent effect variables may have on motor learning (Salmoni et al., 1984). Thus, an experimental design will be used that includes an acquisition period, rest period, retention, and transfer test. The rest period of 48 hours will allow the temporary effects of such variables to dissipate with the retention test being the true test of the effect of practice on motor learning.

At the time of the long-term retention test, participants will also be tested on a transfer task to determine the influence of practicing the arm-reaching tasks (simple and complex) on performance of a standardized test of manual dexterity. Use of the transfer test provides for a test of external validity or generalization in that practice or experience of one type of task may influence the performance of another, different task (Campbell & Stanley, 1963; Schmidt & Young, 1987).

Compliance and Attrition: Threats to Internal Validity

Extended practice or training studies may demonstrate larger rates of subject attrition than short-term or one-time experiments due to the increased probability for problems relative to attendance, sustained motivation, and degree of effort required. Mechanisms to enhance learning and foster subject compliance with attendance; participation; and deliberate, effortful practice (Ericsson et al., 1993) include increasing meaningfulness of the research to the subject (Ericsson et al., 1993; Thomas & Nelson, 1990) and providing motivational feedback during practice (Salmoni et al., 1984). Consideration has been given to these factors by: (1) providing the subject with instructions emphasizing the need for attention to the task and exertion of effort to improve performance (Hilgard & Bower, 1975); (2) providing verbal reminders during the study to maintain attention, focus, and effort; (3) giving verbal feedback concerning performance progress throughout practice sessions (Newell, Quinn, Sparrow, & Walter, 1984; Stelmach, 1970); (4) offering individual performance results to each participant following completion of the entire study; (5) compensating all participants $50.00 for completion of the study, and (6) providing an additional monetary incentive whereby the participants (one with and one without PD) with the fastest response times after practice will receive an extra $50.00.

Practical considerations have also been given to selection of study sites with convenient parking and building access.

Persons with PD are likely to have more difficulty with compliance than control participants due to greater potential for illness, effects of medication, off days, and a higher demand on activity for participation. For these reasons, alternative plans must be addressed for possible drop-outs, no-shows, or late arrivals. Should participants be delayed for their appointment, first, every accommodation will be made to see them on that same day, and second, they will be re-scheduled for the next earliest appointment day. Should participants not return for their final posttest, data will be maintained and recorded.

Preliminary Studies

Six preliminary studies were performed to pilot the task, testing apparatus, procedure, recording devices, and data identification. The objectives of these studies, findings, and subsequent decisions made concerning the methods are included in this section.

Preliminary Study 1

Objective. The objective of this pilot was two-fold: (1) to assess the use of the Biopac computerized physiological recording system in collecting and analyzing the stimulus response signal and EMG signals, and (2) to determine the muscles involved in initiating the first movement component of the testing movements (a lateral 12.7 cm hand displacement, moving right to left).

Findings. Both onset signal and EMG data were recorded successfully. The biceps and deltoid muscles were determined to be active initiating and performing the test movement. The ground electrode will be best placed on the left lower or upper extremity to avoid interference when performing the arm-reaching tasks.

Decisions. The experimenter will need to assess: (1) the efficiency of the Biopac system for continuous testing and recording of data and (2) determine the specific muscle initiating the first movement component of the test task.

Preliminary Study 2

Objective. The objective of the second pilot was to assess the test apparatus, specifically the telegraph key-like switches, the response stimulus signal, and onset switch with the Performance Pack (sequential timer and recorder). Each "telegraph key" switch was composed of a microswitch secured in a fabricated wood base (approximately 7.5 cm square) with a wooden lever and round, one inch wide target. The target was painted bright orange and the housing apparatus beige. The task was arranged in accordance with Light et al. (in press) with a simple and complex movement. The subject (55 year old, female, novel to the task) performed 10 trials each of the simple and complex movement under choice-RT conditions with a variable warning signal of 1 - 4 seconds.

Findings. The subject reported that the switches appeared to be sticking. The switches remained in the closed position after being hit and did not return to the open starting position. The response stimulus light was effective with a yellow light indicating a simple movement response and the red light indicating a complex movement response. The color of the light was changed by a manual switch. The sound of the switch changing the color may pose as an auditory cue to an astute subject that the stimulus and response are being changed. The sound of the switch would need to be dampened or switched randomly and repetitively to prevent its potential use as a cue. The external onset switch, simultaneously starting the stimulus response light and Performance Pack timer, was a standard foot switch (Lafayette Instruments). The subject also reported that the sound of the foot switch closing posed as a response cue prior to activation of the light. A silent external switch would need to be used. The testing procedure was inadvertently examined during this pilot. The experimenter observed that providing verbal RT feedback, after every trial, under choice-RT conditions was confusing to the subject. Furthermore, the experimenter began to develop consistent instructions and set-up procedure for positioning the subject to the apparatus.

Decisions. Data from this subject was not reliable due to the observed and reported mechanical difficulties. The data is thus not reported. The wooden, fabricated switches were reworked but the switching device within the key-like apparatus never functioned satisfactorily. Exploration of several alternative manufactured switches (Lafayette, Able-Net, and Du-It) comparing durability, ease of mounting, cost, availability, appearance, target size, and closing force resulted in the purchase of six "jelly bean" switches from Able-Net. Several external switches were examined to start the Performance Pack timer including the internal switch itself. No decision was made at this time. To increase the effectiveness of feedback, trials with summary feedback for 5 trials of each simple and complex movement, after a block of 10 trials under CRT conditions, would be used in a future pilot.

Preliminary Study 3

Objective. The objective of this study was to assess: (1) the two testing movements for a complexity effect, (2) the instructions to the subject, and (3) positioning of the subject. The movements were a simple and complex movement (Light et al., in press). The simple movement was a lateral move of 12.7 cm right to left and the complex movement consisted of the simple movement and two additional movements with two directional changes. A third movement was piloted consisting of the simple movement and three additional movements with three directional changes. Two male subjects (mean age 36 years) were tested for 30 trials under choice-RT conditions. The first subject (W.) performed the 3-part complex movement and the second subject (C.) performed the 4-part complex movement. Two testing positions were piloted: finger tips on the switch versus the flat palmar surface of the fingers with the distal forearm supported.

Findings. W. reported, that regardless of which light came on, he could start to move due to the identical first component of the two movements, then adjust if he needed to continue the movement for the complex task. He was not convinced that he consistently used this strategy, but was aware of it as an option. W. reported that the chair and testing surface needed to be stabilized and that emphasizing a stretch of the arm during the minute rest periods may be beneficial. Summary feedback after a 10 trial block, distinguishing RTs for simple and complex movements, was effective. A complexity effect was not found for the simple and complex movements under the choice-RT conditions for W. (simple: 374 ms RT, complex: 303 ms RT) and for C. (simple: 292 ms RT, complex: 302 ms RT) performing 15 trials of each movement. The palmar, flat finger position appeared to require less dexterity and accuracy and was reportedly less fatiguing.

Decisions. Instructions were standardized to "complete the movement as quickly as you can" to focus the subject's attention on performing each entire movement (Chamberlain & Magill, 1989). Testing will continue under simple RT conditions to decrease the variability in responses (versus alternatively increasing the number of test trials) and to account for potential confounding of the complexity effect (response programming) with difficulties in response selection in persons with PD (Cooper et al., 1994). The supported arm position with flat fingers will be used and is expected to facilitate a quieter baseline for EMG activity at rest.

Preliminary Study 4

Objectives. The purpose of this study was to assess the arm-reaching movements for a complexity effect. Seven participants (5 females and 2 males, mean age 37 years, range 33 - 42 years) completed 20 trials each of the simple movement and the complex movement (three directional changes, four movement components) under SRT conditions. Trials were presented in blocks of 10 trials, changing movements after every block (Barth-Neander, Hynes, & Gentile, 1994).

Findings. The descriptive data for the (1) simple movement RTs were M = .208 s, SD: .049 s, and range: .128 - .264 s and for the (2) complex movement RT M = .252 s, SD: .05 s, and range .159 - .321 s. A 2 X 2 (Complexity X Trial Block) completely repeated ANOVA was significant for the main effect of complexity, F (1,24) = 5.10, $p <$ .033. Thus, faster RTs were observed for participants performing the simple movement compared to the complex movement.

Decision. As a complexity effect was demonstrated for the piloted tasks, the same tasks will be used for this study.

Preliminary Study 5

Objective. The purpose of this study was to confirm which arm muscles initiated the experimental tasks: simple and complex arm-reaching tasks. Surface EMG electrodes were placed on the biceps and anterior deltoid muscles of two female participants: age 32 and age 72. Both movements were performed in response to a verbal ready signal and the variable-onset (1-4 s) auditory "go" signal (buzzer). EMG activity was recorded and collected simultaneously for both muscle groups via Therapeutics Unlimited, Inc. and the Biopac AcqKnowledge data collection and analysis system.

Findings. Identification of EMG onsets determined simultaneous onset of both anterior deltoid and biceps muscle activity for performance of the simple and complex movements (first movement component). (See Figures 10 and 11).

Decision. EMG electrodes will be maintained on the biceps muscle as indicative of muscle activity onset for both the simple and complex arm-reaching tasks of this study.

Preliminary Study 6

Objective. The purpose of the final preliminary study was to complete full testing and practice of the arm-reaching movements (simple and complex) including data acquisition and recording for two participants. The participants were two females, 32 (TL) and 72 (MW) years old. On Day 1, the participants performed: (1) the Box and Block test of manual dexterity, (2) 20 practice trials of each movement: simple and complex, and (3) 80 practice trials each of the two movements in blocks of 10 trials, alternating movement types. For practice trials, summary feedback concerning response times was provided to each subject after each block of trials for even-numbered trials only. On Day 2, 80 more practice trials of each movement were performed as on Day 1. On Day 3, posttests identical to Day 1 were performed. Warning intervals were randomized for 1 - 4 seconds throughout testing and practice sessions .

Findings. Figure 12 (A and B) illustrates one example of collected response stimulus and switch onset signals (upper channel) and EMG signals (lower channel) for the pre- and post-test performance of the simple movement for subject MW. Figure 13 (A and B) also identifies the response stimulus onset, switch onsets, and EMG signals for the pretest and posttest performance of the complex movement for subject MW. Premotor RT, motor RT, RT, MT, and response time intervals are labeled. Pretest and posttest mean values (seconds) for each dependent variable for the two participants, MW and TL, are listed in Table 9. Pretest and posttest results of the BBT transfer task are reported in Table 10.

Decisions. Full testing and practice sessions were completed including data collection and recording. The procedures for testing, practice, EMG onset designation, and data identification from recordings were standardized.

Table 9.

Mean Premotor Times, Motor Times, Reaction Times (RT), Movement Times (MT) and Response Times (RespT) for Pretest and Posttest, Simple and Complex Movements.

Test		Times (s)				
		Pre-motor	Motor	RT	MT	RespT
Simple pre-test						
	MW	.176	.067	.243	.216	.452
	TL	.122	.08	.209	.086	.29
Simple post-test						
	MW	.116	.052	.168	.115	.283
	TL	.106	.083	.196	.065	.261
Complex pre-test						
	MW	.161	.079	.245	1.06	1.25
	TL	.140	.094	.228	.593	.82
Complex post-test						
	MW	.102	.056	.128	.722	.877
	TL	.116	.089	.2	.509	.708

Table 10.

Pretest and Posttest scores (# blocks) on the Box and Block Test (BBT).

	Test	
Subject	Pre-test	Post-test
MW	69	77
TL	96	95

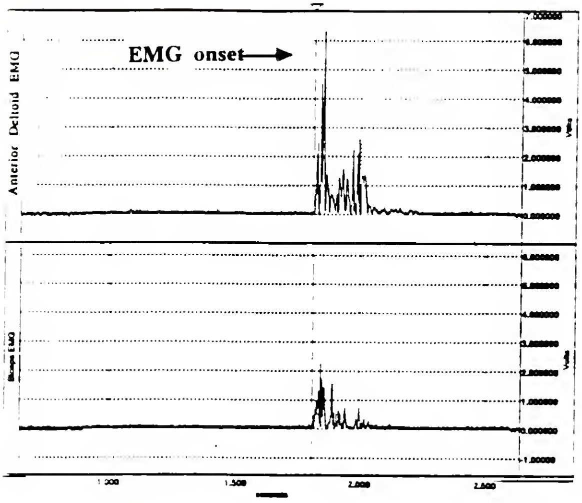

Figure 10. Electromyographic activity and onsets for right anterior deltoid and biceps muscles during performance of simple arm-reaching movement.

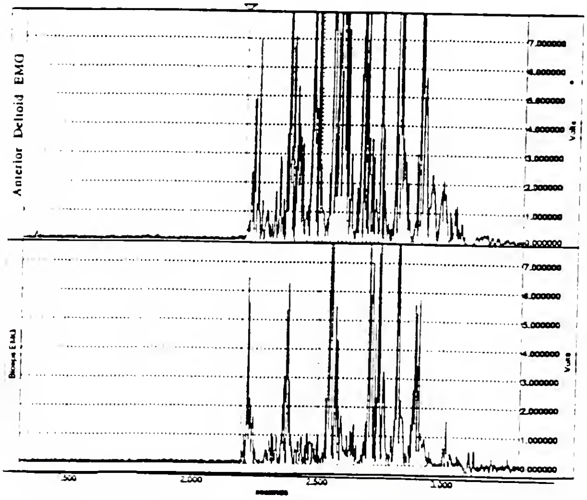

Figure 11. Electromyographic activity and onsets for right anterior deltoid and biceps muscles during performance of complex arm-reaching movement.

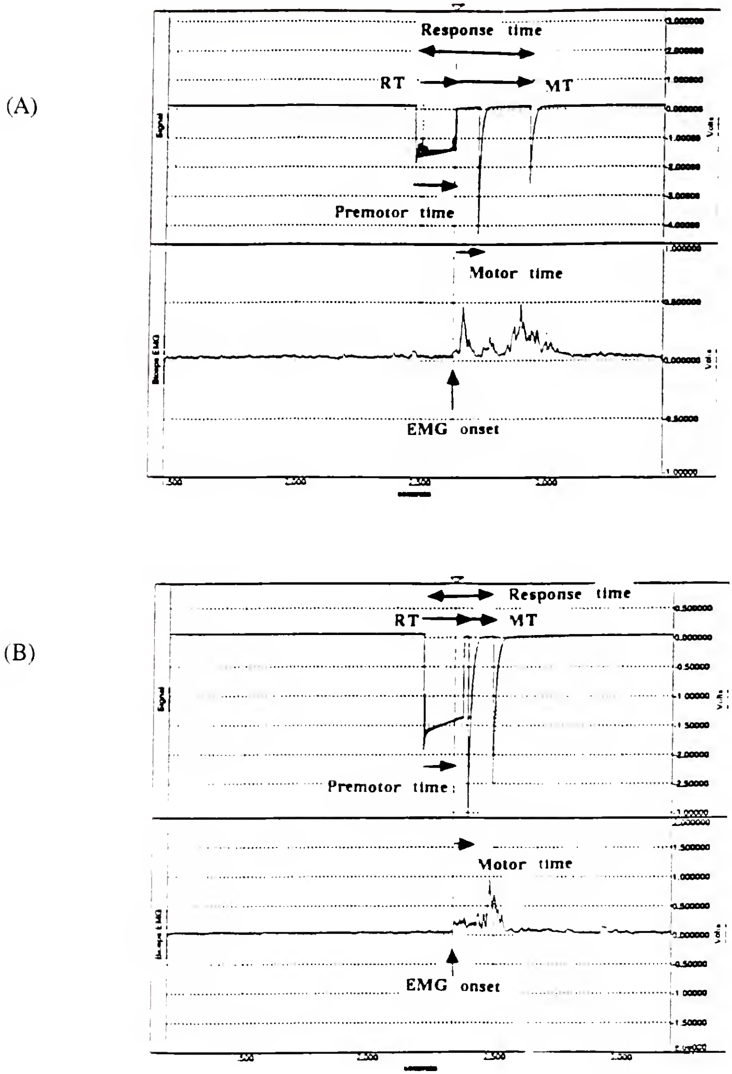

Figure 12. Response movement component time intervals for the right biceps muscle during performance of the simple arm-reaching movement during the pre-test (A) and post-test (B). The upper channel indicates response stimulus onset and switch contact times. The lower channel indicates biceps EMG activity.

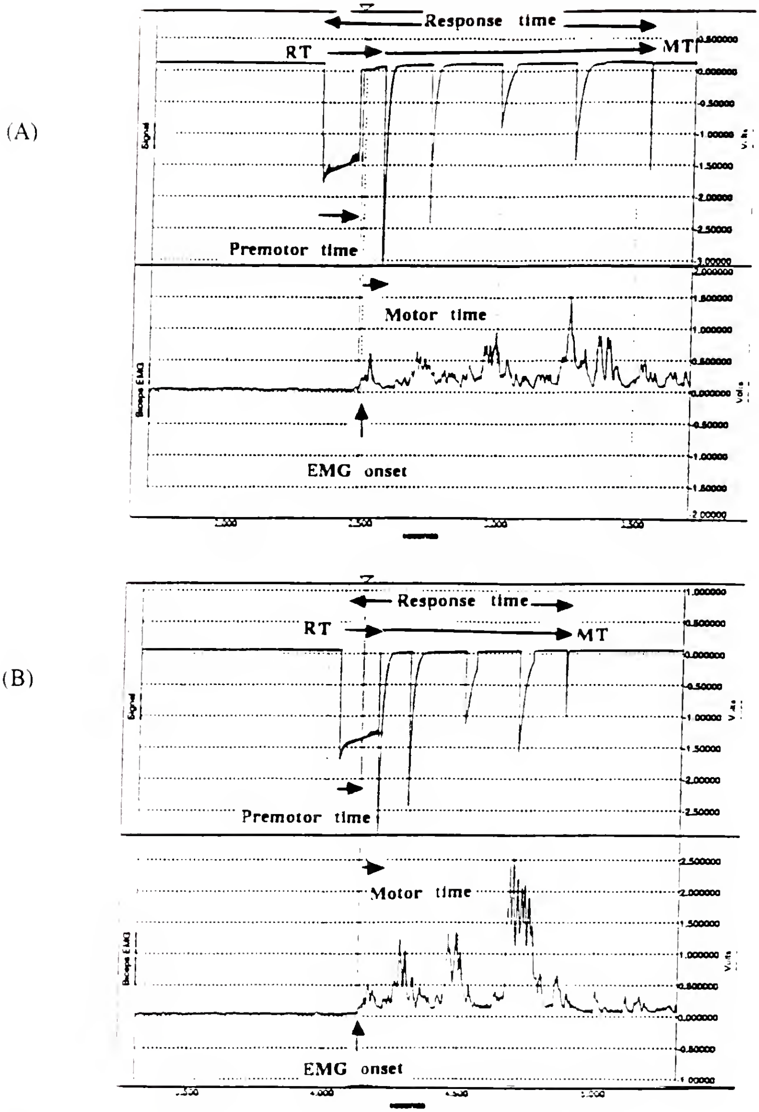

Figure 13. Response movement component time intervals for the right biceps muscle during performance of the complex arm-reaching movement during the pre-test (A) and post-test (B). The upper channel indicates response stimulus onset and switch contact times. The lower channel indicates biceps EMG activity.

APPENDIX H

DESCRIPTIVE DATA FOR COEFFICIENTS OF VARIATION FOR REACTION TIME, PREMOTOR TIME, MOTOR TIME AND MOVEMENT TIME

Table 11. Descriptive Data for Reaction Time Mean Coefficients of Variation for Simple and Complex Arm-reaching Tasks for Groups: Parkinson's Disease and Control

	Simple Arm-reaching Task						Complex Arm-reaching Task					
	Pretest		Imme Retention		Del Retention		Pretest		Imme Retention		Del Retention	
RT CV	PD	Control	PD	Control	PD	Control	PD	Control	PD	Control	PD	Control
Mean	.173	.179	.123	.12	.143	.124	.187	.187	.149	.125	.145	.149
SD	.059	.057	.05	.051	.057	.049	.074	.074	.058	.048	.065	.057
Range	.1 - .3	.09 - .3	.05 - .2	.06 - .2	.06 - .2	.06 - .2	.1 - .3	.1 - .3	.05 - .2	.07 - .2	.08 - .3	.07 - .2

Note. RT = reaction time; CV = coefficient of variation; SD = standard deviation; PD = Parkinson's disease; Imme Retention = immediate retention; Del Retention = delayed retention.

Table 12. Descriptive Data for Premotor Time Mean Coefficients of Variation for Simple and Complex Arm-reaching Tasks for Groups: Parkinson's Disease and Control

	Simple Arm-reaching Task						Complex Arm-reaching Task					
	Pretest		Imme Retention		Del Retention		Pretest		Imme Retention		Del Retention	
PreT CV	PD	Control	PD	Control	PD	Control	PD	Control	PD	Control	PD	Control
Mean	.293	.247	.22	.22	.253	.186	.307	.307	.267	.2	.253	.220
SD	.08	.099	.068	.077	.083	.075	.103	.07	.082	.065	.083	.094
Range	.2 - .4	.1 - .5	.1 - .3	.1 - .3	.1 - .4	.09 - .3	.1 - .5	.2 - .4	.1 - .4	.1 - .3	.1- .4	.1 - .4

Note. PreT = premotor time; CV = coefficient of variation; SD = standard deviation; PD = Parkinson's disease; Imme Retention = immediate retention; Del Retention = delayed retention.

Table 13. Descriptive Data for Motor Time Mean Coefficients of Variation for Simple and Complex Arm-reaching Tasks for Groups: Parkinson's Disease and Control

	Simple Arm-reaching Task						Complex Arm-reaching Task					
	Pretest		Imme Retention		Del Retention		Pretest		Imme Retention		Del Retention	
Mot CV	PD	Control	PD	Control	PD	Control	PD	Control	PD	Control	PD	Control
Mean	.227	.171	.193	.171	.233	.136	.227	.192	.219	.152	.219	.156
SD	.07	.073	.08	.073	.091	.055	.11	.072	.08	.053	.079	.068
Range	.1 - .4	.08 - .3	.1 - .4	.07 - .3	.09 - .4	.06 - .2	.1 - .5	.08 - .3	.08 - .3	.09 - .2	.09- .3	.05 - .3

Note. Mot = motor time; CV = coefficient of variation; SD = standard deviation; PD = Parkinson's disease; Imme Retention = immediate retention; Del Retention = delayed retention.

Table 14. Descriptive Data for Movement Time Mean Coefficients of Variation for Simple and Complex Arm-reaching Tasks for Groups: Parkinson's Disease and Control

	Simple Arm-reaching Task						Complex Arm-reaching Task					
	Pretest		Imme Retention		Del Retention		Pretest		Imme Retention		Del Retention	
MvT CV	PD	Control	PD	Control	PD	Control	PD	Control	PD	Control	PD	Control
Mean	.18	.131	.163	.165	.156	.167	.085	.066	.045	.047	.051	.041
SD	.068	.05	.054	.063	.057	.072	.049	.018	.021	.019	.02	.016
Range	.1 - .3	.09 - .2	.07 - .2	.08 - .3	.07 - .2	.1 - .3	.04 - .2	.03 - .1	.01 - .09	.03 - .09	.03- .1	.02 - .08

Note. MvT = movement time; CV = coefficient of variation; SD = standard deviation; PD = Parkinson's disease; Imme Retention = immediate retention; Del Retention = delayed retention.

APPENDIX I

COEFFICIENTS OF VARIATION FIGURES FOR REACTION TIME, PREMOTOR TIME, MOTOR TIME, AND MOVEMENT TIME ANALYSES

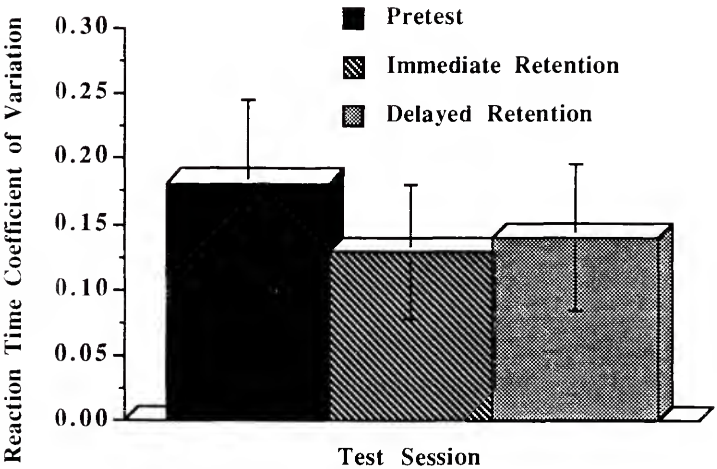

Figure 14. Reaction time mean coefficients of variation and standard deviations for test session effect.

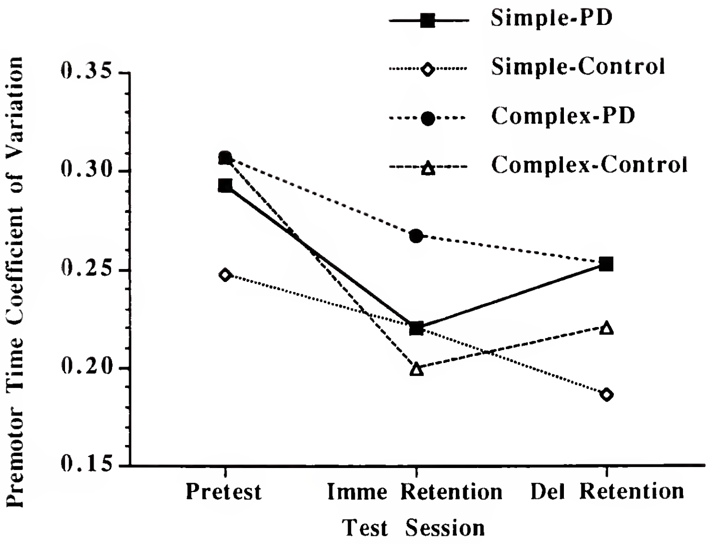

Figure 15. Premotor time mean coefficients of variation for group x complexity x test session interaction. Imme = immediate. Del = delayed.

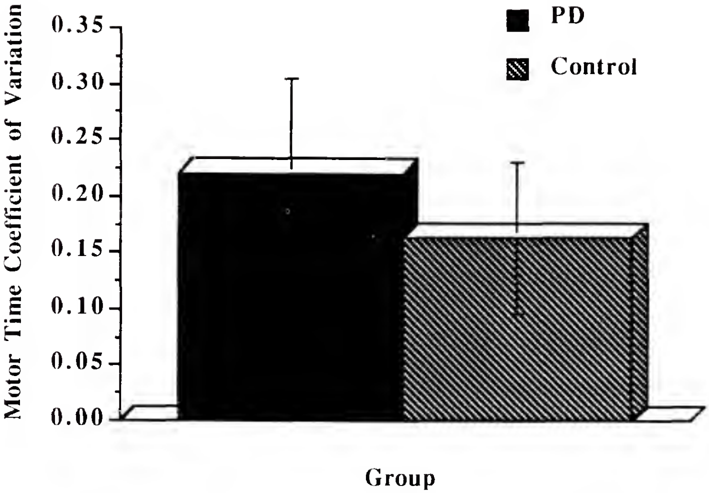

Figure 16. Motor time mean coefficients of variation and standard deviations for group effect. Imme = immediate. Del = delayed.

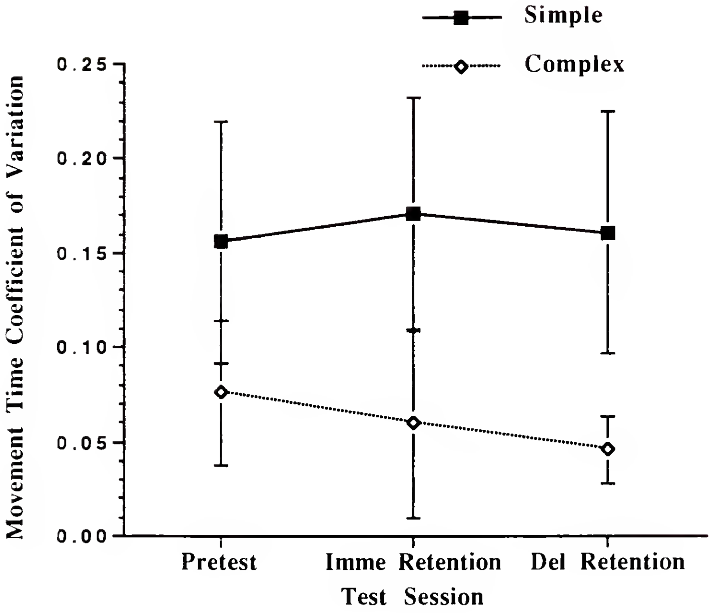

Figure 17. Movement time mean coefficients of variation and standard deviations for complexity x test session interaction. Imme = immediate. Del = delayed.

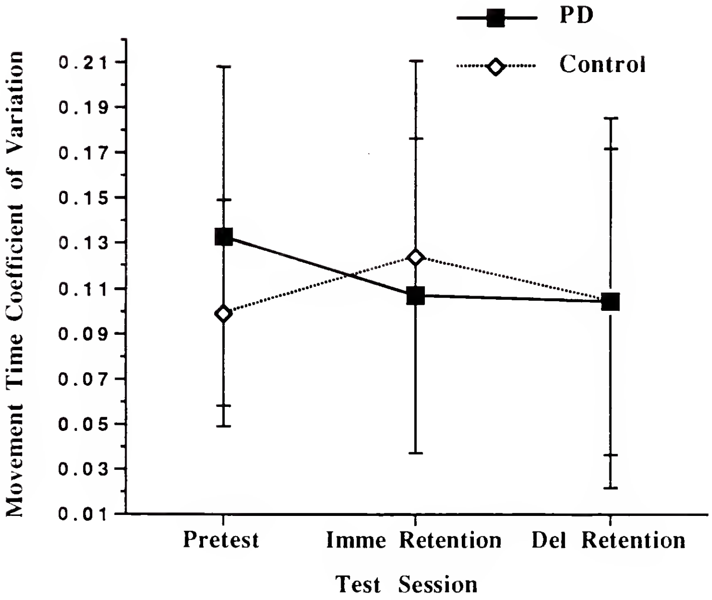

Figure 18. Movement time mean coefficients of variation and standard deviations for group x test session interaction. Imme = immediate. Del = delayed.

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BIOGRAPHICAL SKETCH

Andrea Louise Behrman was born on May 18, 1954 in Lexington, Virginia, to Jack and Louise Behrman. She has two siblings, Douglas Behrman and Gayle Behrman Jaster. After graduating from Chapel Hill High School in 1972, she attended Furman University in Greenville, South Carolina. She received the degree of Bachelor of Science, cum laude, in biology in 1976. She entered graduate school in 1978 at Duke University and completed a Master of Science in Physical Therapy in 1980. She was employed for one year as a physical therapist at Memorial Mission Hospital in Asheville, North Carolina. From 1981 through 1987, she was employed as a staff physical therapist, supervisor, and director of physical therapy at Woodrow Wilson Rehabilitation Center in Fishersville, Virginia. Her interest in adult neuro-rehabilitation developed in this clinical setting. She was employed as an Assistant Professor in the Department of Physical Therapy at Beaver College in Glenside, Pennsylvania, from 1987 to 1991. She entered the Graduate School of the University of Florida in August, 1991 to study motor behavior as a full-time doctoral student in the College of Health and Human Performance, Department of Exercise and Sport Sciences.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

James H. Cauraugh

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